Sascha L. Schmidt *Editor*

21st Century Sports

How Technologies Will Change Sports in the Digital Age

Second Edition

Springer

Future of Business and Finance

The Future of Business and Finance book series features professional works aimed at defining, analyzing, and charting the future trends in these fields. The focus is mainly on strategic directions, technological advances, challenges and solutions which may affect the way we do business tomorrow, including the future of sustainability and governance practices. Mainly written by practitioners, consultants and academic thinkers, the books are intended to spark and inform further discussions and developments.

Sascha L. Schmidt
Editor

21st Century Sports

How Technologies Will Change Sports in the Digital Age

Second Edition

Springer

Editor
Sascha L. Schmidt
Center for Sports and Management
WHU—Otto Beisheim School
of Management
Dusseldorf, Germany

Foreword by Ralf Reichert

Sports have been a staple of human society for centuries, with roots in fighting culture and medieval horseback competitions. As time passed, sports evolved into organized games with rules and competitive structures that changed dramatically. From the likes of football, basketball, and cricket to the recent rise of esports, the evolution of sports has been nothing short of captivating.

But the transformation doesn't seem to be slowing anytime soon. In fact, with the rapid advancement of technology, the 21st century promises to be a game-changer in how athletes perform and how fans engage with sports. One of the most significant impacts of technology has been the rise of esports. Although it took almost two decades for society to accept esports as a legitimate sport, it is now a thriving industry with millions of players and spectators worldwide.

Moreover, the prospect of traditional sports merging with esports in the "metaverse" is tantalizing. The metaverse is a virtual world where people can interact in real-time, and with the rise of virtual reality technology, it has the potential to revolutionize the sports industry. Imagine watching a football game in the metaverse with players appearing as avatars, or even competing in an esports game yourself in the same virtual world. The possibilities are endless, and it's just the tip of the iceberg.

Technological advancements in athletic performance are also on the rise. Wearable devices like smartwatches, fitness trackers, and heart rate monitors are ubiquitous in sports, providing athletes with real-time data on their performance. But as we delve deeper into tech integration like augmented reality, embedded sensors, and exoskeletons, the potential for disruption in all aspects of sports is enormous. The impact of these devices on the future of sports is a topic that demands exploration, and this book provides valuable insights.

Finally, it's not just about the athlete; it's about the fan. Technology is already transforming fan engagement, making it easier than ever for fans to connect with their favorite athletes and teams. The live event experience is also improving, and the possibilities for engagement are expanding beyond playing and watching. The metaverse offers a cohesive digital destination and community that can take fan engagement to new heights, much like the popular game Fortnite.

All of these exciting prospects and more are covered in the must-read book, "21st Century Sports—How technology will change sports in the digital age." Whether you're an avid sports fan or just curious about the future of sports, this book offers valuable insights into how technology will shape the future of sports.

Ralf Reichert
CEO
Esports World Cup Foundation
Cologne, Germany

Foreword by Carsten Cramer

Why am I pleased to not only have had the opportunity to read this book, but also to write a foreword for it?

There are several reasons for this, including interest in the topic itself, the aspiration to position oneself in a way that is fit for the future, and, above all, admiration for the editor of this book. I have known and appreciated Sascha L. Schmidt for a long time and the way he and his team approach future-related topics has always interested and inspired me. They have repeatedly opened my eyes to the fact that, at times, we need a provocative view from outside the football industry in order not to remain or become blind to change and innovation. After all, the full stadiums, high membership figures, and high media coverage we currently enjoy are not guaranteed for any amount of time, especially given the behavioral patterns of the younger generation.

I started my career in classical sports marketing. Possibly, in view of my own advanced age, I think and act in a somewhat more traditional way—and I confess to not thinking boldly and resolutely enough about change here and there. Moreover, as the managing director of a traditional football club, I am also subject to certain constraints. On the other hand, there is Sascha and his team, who keep presenting change and innovation to the established football business. They help me and my team to address the following questions: How much innovation can a club like Borussia Dortmund tolerate? How much stretching can a football brand like BVB manage? How can we, as Borussia Dortmund, benefit from changes and new trends without losing focus or face?

To answer these and other questions, we launched a "black-and-yellow" future workshop series inspired by *21st Century Sports—How Technology Will Change Sports in the Digital Age.* In this series, we consider technologies and innovations, discuss them in a controversial manner, and question what suits BVB and how. Through this scientifically supported, technology-driven, and data-based approach, I see the opportunity for our club to innovate rather than unnecessarily reinvent itself. And, in sparring with the WHU team, I have confidence in the new perspectives that will inevitably arise for our cooperation.

I am very grateful to Sascha L. Schmidt for compiling this fantastic collection of insightful essays by thought leaders in their respective fields. This book offers us a valuable outside perspective and will find an eager readership around the globe.

Carsten Cramer
Managing Director
Borussia Dortmund
Dortmund, Germany

Preface

We are thrilled to report that since we launched the first edition of 21st Century Sports two and a half years ago, the book has been downloaded or sold more than 60,000 times worldwide! We were able to translate the book into Mandarin, thanks to our partnership with Tsinghua University Press, and it received overwhelming support in China. We were delighted to develop an online course, "Transactional Technologies—Applied Lessons from Sports," with MITxPro; we extend our gratitude to chapter authors Christina Chase, Ben Shields, and Josh Siegel for teaching technologies based only on sports examples. As if that weren't enough, we also created a popular YouTube video with Athletic Interest, viewed over 450,000 times, which addressed the question of why soccer will end in 2049. Lastly, the book has inspired an esports/metaverse documentary and even a fictional series—we can't wait to share more about them in the next edition of the book!

In the first edition's Preface, I ended by saying that the future of sports technology will be wilder than we could ever imagine. Recent events have proven this to be true. The COVID-19 pandemic posed a significant challenge to the sports industry, leading to the postponement of the 2020 Olympic Games and the 2020 UEFA European Football Championship. Many sporting events were held without fans or with limited attendance; as a result, sports organizations have had to lay off staff, reduce salaries, and even file for bankruptcy. But, the pandemic also forced organizations to find new ways to engage with fans through digital platforms and immersive technologies. This convergence of digital and physical reality in the so-called metaverse has brought about a paradigm shift in the sport industry.

In 2023, we're in the middle of a game-changing process toward a digital universe of interconnected worlds. This future digital universe is enabled by technologies like AI, blockchain, computer vision, edge computing, IoT, and robotics that interconnect physical, data processing, and human interaction technologies. AI has garnered a lot of attention recently, and it plays an important role in developing the metaverse, enhancing user interactions, creating digital human replicas, designing flexible user interfaces, and ensuring data security. Though we're not there yet, thousands of digital worlds, such as Decentraland, Roblox, Somnium Space, and VR Chat, are being developed. Soon, these digital worlds will be interconnected, enabling us to traverse them with our avatars, much like how we switch web pages.

The metaverse has gained a lot of attention lately, especially after Meta changed its name in 2021. Sports brands like Adidas, Nike, Puma, Manchester City, and McLaren are now exploring the possibilities of using the metaverse and related technologies to connect with people in the digital space. Manchester City has started creating virtual replicas of its stadium to allow fans from around the globe to visit via digital avatars. Other football clubs like FC Arsenal, Juventus Turin, Paris St. Germain, and Borussia Dortmund have partnered with crypto companies to offer fans exclusive access, such as NFTs and VIP tickets. The NBA has also teamed up with Dapper Labs to develop NBA Top Shot, a blockchain-based platform for buying, selling, and trading officially licensed NBA collectibles. As technology advances, sports organizations will continue to embrace the metaverse and related technologies to engage with their fans in new and innovative ways.

The metaverse had a lot of initial hype, but stock and cryptocurrency prices have dropped significantly since its debut. Big companies like Disney and Microsoft have scaled back their metaverse projects with layoffs and shutdowns; even Mark Zuckerberg is rethinking his metaverse strategy. However, this is all part of the normal hype cycle of a technology, and it's clear that the metaverse is here to stay, even if we don't know yet what business models will work. The uncertainty surrounding the metaverse, however, raises questions about value creation in a digital society; and we have invited thought leaders to add essays to our book's second edition to explore these topics and what they mean for athletes, fans, and management.

Since the first edition of the book, much has changed and much remains the same. Athletes still push themselves to be the best they can be and sports business leaders must innovate and stay ahead of the competition. However, in today's uncertain world, this can be a challenging task. In the second edition of the book, my co-authors and I look to the future, examining how new technologies will change the sports industry, consumer behavior, and existing business models. We hope this book will serve as a compass for the next five to ten years, and beyond.

We are proud of our international, multi-professional author team from renowned institutions such as Massachusetts Institute of Technology, Queensland University of Technology, Stockholm School of Economics, and the University of Cambridge, as well as international thought leaders with deep technological expertise. They contribute profound technological knowledge and an ability to anticipate trends; analyze their impact on athletes, fans, and management; and devise effective strategies to stay ahead of the competition. Despite the uncertainties of our new reality, the relationship between sports and technology is growing stronger, making this an exciting and economically and socially significant time for the industry.

Dusseldorf, Germany   Sascha L. Schmidt

Acknowledgements

Contents

Information Processing Technologies

Human Interaction Technologies

Technology Convergence

Contributors

Michael Bartl TAWNY and HYVE, Munich, Germany

Daniel Beiderbeck Center for Sports and Management, WHU—Otto Beisheim School of Management, Dusseldorf, Germany

Martin Carlsson-Wall Center for Sports and Business, Stockholm School of Economics, Stockholm, Sweden

Simon Chadwick SKEMA Business School, Paris, France

Christina Chase MIT Sports Lab, Massachusetts Institute of Technology, Cambridge, MA, USA

Alex Fenton Digital Business, University of Salford School of Business, Manchester, UK

Nicolas Frevel Center for Sports and Management, WHU—Otto Beisheim School of Management, Dusseldorf, Germany

Johann Füller HYVE, Innsbruck University, Innsbruck, Austria

Craig Hill Australian Sports Technologies Network, Melbourne, Australia

Dietmar W. Hutmacher Institute of Biomedical Innovation, Queensland University of Technology, Brisbane, Australia;
Australian Research Council Industrial Transformation, Training Centre for Additive Biomanufacturing, Kelton Grove, Australia

Sandy Khaund Credenza, San Francisco, CA, USA

Frank Kirchner Robotics Innovation Center, DFKI Bremen, University of Bremen, Bremen, Germany

Harry Krüger Center for Sports and Management, WHU-Otto Beisheim School of Management, Dusseldorf, Germany

Jordi Laguarte Soler MIT Auto-ID Laboratory, Cambridge, MA, USA

Andy Miah Science Communication & Future Media, University of Salford School of Science, Engineering and Environment, Manchester, UK

Tim Minshall Institute for Manufacturing, IfM's Centre for Technology Management, University of Cambridge, Cambridge, UK

Daniel Morris Electrical and Computer Engineering, Michigan State University, East Lansing, MI, USA

Brianna Newland Undergraduate Programs & Sport Management, Preston Robert Tisch Institute for Global Sport at New York University, New York, NY, USA

Shelly Palmer The Palmer Group, S.I. Newhouse School of Public Communications, Syracuse, New York, NY, USA

Benjamin Penkert SportsTechX GmbH, Berlin, Germany

Johanna Pirker   Graz University of Technology and Game Lab Graz, Graz, Austria

Jason Potts RMIT University Blockchain Innovation Hub, Melbourne, Australia

Amir Raveh HYPE Sports Innovation, London, United Kingdom

Irving Rein Communication Studies, Northwestern University, Evanston, IL, USA

Sanjay Sarma Open Learning and Massachusetts Institute of Technology, Cambridge, MA, USA

Martin U. Schlegel Australian Sports Technologies Network, Melbourne, Australia

Sascha L. Schmidt Center for Sports and Management, WHU—Otto Beisheim School of Management, Dusseldorf, Germany

Dominik Schreyer Center for Sports and Management, WHU—Otto Beisheim School of Management, Dusseldorf, Germany

Ben Shields Managerial Communications, MIT Sloan School of Management, Cambridge, MA, USA

Josh Siegel Computer Science and Engineering, Michigan State University, East Lansing, MI, USA

Katsume Stoneham London, UK

Brian Subirana MIT Auto-ID lab, Massachusetts Institute of Technology, Cambridge, MA, USA

Stuart Thomas RMIT University Blockchain Innovation Hub, Melbourne, Australia

Kieran Tierney RMIT University School of Economics, Finance and Marketing, Melbourne, Australia

Rishad Tobaccowala Rishad Tobaccowala LLC, Chicago, IL, USA

Benno Torgler Centre for Behavioural Economics, Society and Technology (BEST), Queensland University of Technology, Brisbane, Australia

Heiko A. von der Gracht KPMG and Steinbeis School of International Business and Entrepreneurship, Herrenberg, Germany

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, sports consumption, sports management, and governance. He also describes how technology drives the development of new sports and the enhancement of traditional sports. Finally, he outlines the process by which technologies were selected for the second edition of *21st Century Sports: How Technologies Will Change Sports in the Digital Age* as well as the structure and chapters of the book.

1   The Growing Business of Sports

In today's world, sports have become a vast industry that involves a multitude of sectors and markets, employing millions of people worldwide. With various subcategories, it can be challenging to determine the precise size of the global sports industry. However, experts estimate that the sports industry contributes around 1% of the world's GDP when sports infrastructure, events, hospitality, training, and the manufacturing and retail of sports goods are considered (KPMG, 2016; Research & Markets, 2022). Despite the significant impact of the COVID-19 pandemic on the sports industry, it is gradually recovering; and its contribution to the world's GDP is expected to remain proportional (Beiderbeck et al., 2021).

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.

S. L. Schmidt (✉)

Center for Sports and Management, WHU—Otto Beisheim School of Management, Vallendar, Germany
e-mail: sascha.schmidt@whu.edu

3

The increasing number of new and growing sporting mega-events worldwide, for example, led to a global sports sponsoring volume of USD 78 billion in 2022 (Research & Markets, 2022)—despite the COVID-19 pandemic.

With all the excitement for sports, however, we cannot neglect that, from a business perspective, sports is one of the most conservative industries on the planet. In a way, sports 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 competitive dynamics of these two domains and disrupt, albeit temporarily, the competitive balance so important in sports.

Nevertheless, the sports industry is undergoing a period of rapid growth, driven by exciting new technological developments and the rise of data as the new currency in sports (Ratten, 2019). As data analytics continues to evolve, sports act as a proving ground or "laboratory" for new technologies (Michelman, 2019). This has given rise to a flourishing sports tech landscape, with 38 unicorns such as Animoca Brands, Fanatics, OneFootball, DraftKings, or Sorare leading the way. Experts predict that 2021 will be remembered as the year that SportsTech finally hit the big time, with the industry almost reaching the USD 12 billion investment milestone. Of that, more than 60% was invested in fan-focused solutions (Penkert & Malhotra, 2022), reflecting the growing importance of engaging with fans in new and innovative ways.

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.

Professional sports have always benefitted from technology advancements. For example, F1 racing teams have used telemetry since the late 80s to record performances and determine—on the fly—the best car setup the pilot can use. A more modern example is the new high-tech domain of the modern America's Cup; sailing, requires an intricate interplay of software, hardware, electronics, hydraulics, and human input.

Technology and sports have a dynamic relationship. Sports is a proving ground for new technologies and technologies are, at the same time, a major source of disruption in sports. The ways that sports is played by athletes, viewed by consumers, and monetized and regulated by management, are all being revolutionized by the deployment of technological innovations.[1]

---

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

2.1 Technology Improves Athletic Performance

In the past, training and competition preparation were driven by intuitive practices; one followed the tried path without knowing exactly why. Nowadays, athletes—professional, amateur, or leisurely—are increasingly turning to new technologies to get the most out of their physical and mental capabilities and gain competitive advantage. 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 sports 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. These too we explore in this book.

2.2 Technology Improves Sport Consumption

New blockchain-based web3 technologies in combination with mixed reality and artificial intelligence 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 sports consumption experience (Chan-Olmsted & 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 & 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 & Bukstein, 2016). For instance, customized apps help teams or coaches 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 & Chappelet, 2015). In addition, technical solutions can be intended for or related to the media, sponsor brands, and investors (Penkert & 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 (Beiderbeck et al. 2023).

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 also 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. Two decades after Kasparov's defeat in chess, 18-time world champion Lee Sedoll was outmatched in one out of five games against the AlphaGo machine in the Chinese board game Go. Artificial intelligence also defeated humans in games like Jeopardy, poker, and Dota 2, without being explicitly programmed to do so. These programs relied on machine learning to teach themselves the game, a testament to the remarkable potential of artificial intelligence technology.

There have also been interesting human–machine duels, where humans compete against each other indirectly by steering robots. RoboGames, for example, has already hosted competitions 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

---

[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.

team develops itself, the driverless racecars will compete on the asphalt at speeds of up to 300 km/h (Standaert & 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 rise of esports from a small hobby to a huge billion-dollar industry is a clear demonstration of how technology can drive the development of sports. Newzoo (2022) forecast predicts that the revenue generated from esports will grow from 1.4 billion USD in 2022 to 1.9 billion USD in 2025.

Esports is a shining example of how technology is shaping the future of sports. The virtual environment of esports allows for exciting and innovative features that can't be found in traditional sports. And while esports is still relatively small—with only a few thousand professional gamers—its global audience has already surpassed a staggering 530 million in 2022 and is expected to grow to 641 million in 2025. This is due, in part, to the lingering effects of the COVID-19 pandemic and the rise of markets in Southeast Asia, Latin America, and the Middle East and Africa. It's not just a niche group either—esports fans are part of a massive community of 3 billion regular and casual video gamers worldwide.

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. For example, esports were officially added to the Asian Games in 2022 and the International Olympic Committee initiated an esports competition in March 2023.

Other sports, such as drone racing, have grown in recent 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 becoming 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. The past couple of years has seen a surge in the appeal of drone racing, particularly during the pandemic. With the advent of advanced and high-speed drones, coupled with increased investments in flight tech research, the industry has witnessed an upward trend. The emergence of racing leagues and more events has further propelled this growth on a global scale. According to Polaris Market Research (2022), the current worth of the worldwide racing drone market stands at a whopping USD 798 million in 2022, and there are predictions that it will continue to flourish at a promising CAGR of 21% over the next decade.

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 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 to identify technologies, trends, and developments early on and to raise attention to the opportunities and threats associated with them.

3.1   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 amongst 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 (Gartner,) as a basis to select the most relevant emerging technologies for the first edition of the book (Schmidt, 2020). 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. In the second edition of our book, we delved into the latest Gartner *Emerging Technologies Hype Cycle* and compared it to previous years' data (Gartner, 2022). We found that immersive technologies like metaverse, non-fungible tokens (NFTs), and web3 are gaining increasing importance. These cutting-edge technologies provide new avenues for fans to engage and expand user experiences into virtual worlds and digital currencies, potentially leading to new revenue streams. However, it's important to note that these technologies are interconnected, with artificial intelligence, blockchain, and web3 all intertwined. That's why we have included essays that explore these fascinating technological innovations and their convergence.

3.2 Book Structure

We have organized this book into six sections: an introductory section, three sections on technologies, a section on technology convergence, 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 sports. In doing so, they make the case for the application of *Thesis Driven Innovation Radars*.

Finally, Sascha L. Schmidt, Daniel Beiderbeck, and Heiko von der Gracht discuss in "How to Predict the Future of Sports" whether and how the future of sports can be predicted, and which scientific tools and measures exist to foresee the impact of technology on sports in the digital age. They discuss the pros and cons of popular quantitative vs. qualitative forecasting methods. Finally, they outline how to apply the Delphi method and provide empirical results from a number of future studies in sports.

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 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 insurance, stadium setup 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—will be the champions of tomorrow.

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.

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 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, the potential for a hybrid business model, and the geographic footprint. Finally, they look further into the future and see unexpected possibilities for blockchain in sports.

Jason Potts, Stuart Thomas, and Kieran Tierney consider sport as an economy and the impact of innovation, blockchain technology, and its applications, on truth and trust in sports and business models and opportunities. In "Blockchain Innovation in Sports Economies" they discuss blockchains' potential applications in sports—NFTs, DAOs, and web3 chief among them. Finally, with blockchain technology as their new foundation, they imagine the future of sports economies.

IV. Human interaction technologies. This technology category is mainly about human interaction. It plays a particularly important role in, e.g., in 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 costs, 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 experiences that, in turn, transform the sporting world.

Dominik Schreyer discusses in "How Technologies Might Change the European Football Spectators' Role in the Digital Age" whether ever-expanding the seat supply in football clubs will ultimately be sustainable. He questions how technologies might change the European football spectators' role in the digital age, specifically focusing on the potential role of augmented and virtual reality in shaping the stadium experience in 2040. In all, he outlines ten projections, painting a future scenario indicating the European football spectators' loss of significance.

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. Technology convergence. The lines between the different technology categories are becoming increasingly blurred due to the convergence of technologies. AI, blockchain, and web3 technologies are all merging into a new realm called the metaverse. This exciting new space is helping to create a virtual universe, where we are building a new civilization. The foundation of this 3D internet is gaming, and major publishers such as Microsoft's Activision Blizzard, Riot Games, Tencent Games, and Valve are leading the way. These companies have created their own ecosystems with their own rules and governance, and the same principles apply to the architects of the new virtual universe. As the world continues to be captivated by the rise of immersive technologies and the intermingling of data processing technologies with human interaction technologies, we felt compelled to expand our book with a new section dedicated to exploring the exciting phenomenon of technology convergence.

In "Sports in the Third Connected Age," Rishad Tobaccowala looks back on how sports were impacted by the first two connected ages and forward to the key changes expected to sports fan experience, the monetization of sports, and the nature of sports in the Third Connected Age. He also explores the implications and ramifications of this new age for sports leaders. Finally, he outlines three key steps for future success: changing thinking, investing in education, and focusing on partnerships.

In his chapter, "Navigating the web3 Landscape: a Forward-Looking Perspective on the Future of Sports Business for Athletes, Consumers, and Management," Amir Raveh introduces and emphasizes the importance of GenAlpha in guiding decision-making and dives into the fundamentals of web3 technology and

its potential applications for community building in the sports business. Finally, he discusses the impact of web3 technology on sports consumption, athletes, and management, as well as its potential for growth in the global sports technology startup scene.

In "Imagining the Future of Fandom," Shelly Palmer discusses how fans would attend a sporting event or concert if there were no technical or financial constraints. He elaborates on what "attending" might mean by painting a picture of a future in which fans have access to the data coaches during the game and digital twins of their game-worn collectibles in a virtual world. Also possible in this future, star players might appear to fans as full-motion holograms, avatars, or synthetic humans.

VI. 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," Katsume Stoneham and I 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.

References

Beiderbeck, D., Frevel, N., von der Gracht, H., Schmidt, S. L., & Schweitzer, V. M. (2021). The impact of COVID-19 on the European football ecosystem—A Delphi-based scenario analysis. *Technology Forecasting and Social Change, 165*, 120577.

Beiderbeck, D., Evans, N., Frevel, N., & Schmidt, S. L. (2023). The impact of technology on the future of football—A global Delphi study. *Technology Forecasting and Social Change, 187*, 122186.

Cetron, M. (1970). A Method for integrating goals and technological forecasts into planning. *Technology Forecasting and Social Change, 2*(1), 23–51.

Chan-Olmsted, S., & Xiao, M. (2019). Smart sports fans: Factors influencing sport consumption on smartphones. *Sport Marketing Quarterly, 28*(4), 181–194.

Crouse, K. (2009). Swimming Bans High-Tech Suits, Ending an Era. https://www.nytimes.com/2009/07/25/sports/25swim.html. Accessed 16 Apr 2020.

Düking, P., Stammel, C., Sperlich, B., Sutehall, S., Muniz-Pardos, B., Lima, G., Kilduff, L., Keramitsoglou, I., Li, G., Pigozzi, F., & Pitsiladis, Y. P. (2018). Necessary steps to accelerate the integration of wearable sensors into recreation and competitive sports. *International Perspectives, 7*(6), 178–182.

Gartner. (2017, 2018, 2019, 2022). *Gartner hype cycle for emerging technologies.* Gartner Inc.

Ha, A. (2020). AKQA says it used AI to invent a new sport called Speedgate. https://techcr unch.com/2019/04/11/akqa-says-it-used-ai-to-invent-a-new-sport-called-speedgate/. Accessed 24 Jan 2020.

Harari, Y. N. (2016). *Homo Deus: A brief history of tomorrow*. Harvill Secker.

Harrison, K., & Bukstein, S. (2016). *Sport business analytics: Using data to increase revenue and improve operational efficiency*. Auerbach Publications.

Hienerth, C. (2006). The commercialization of user innovations: The development of the rodeo kayaking industry. *R&D Management, 36*(3), 273–294.

Hienerth, C., von Hippel, E., & Berg Jensen, M. (2014). User community vs. producer innovation development efficiency: A first empirical study. *Research Policy, 43*, 190–201.

Jung, S., Hwang, S., Shim, D. H., & Shin, H. (2018). Perception, guidance, and navigation for indoor autonomous drone racing using deep learning. *IEEE Robotics and Automation Letters, 3*(3), 2539–2544.

Kopacek, P. (2009). Automation in sports and entertainment. In S. Y. Nof (Ed.), *Springer handbook of automation* (pp. 1313–1331). Springer.

KPMG. (2016). *The business of sports: Playing to win as the game unfurls*. KPMG.com/in.

Kyodo News. Paralympics: Blade jumper Markus Rehm chases able-bodied world record. https:// english.kyodonews.net/news/2019/08/256037e97f02-paralympics-blade-jumper-rehm-chases-able-bodied-world-record.html. Accessed 28 Aug 2019.

Lombardo, M. P. (2012). On the evolution of sport. *Evolutionary Psychology, 10*(1), 1–28.

Michelman, P. (2019). Why sports is a great proving ground for management ideas. *MIT Sloan Management Review,* Online: Retrieved September 26, 2023, from https://sloanreview.mit.edu/article/why-sports-is-a-greatproving-ground-for-management-ideas/

Newzoo. (2022). Global esports & live streaming market report, Amsterdam.

Parent, M., & Chappelet, J.-L. (2015). *The Routledge handbook of sports event management*. Routledge.

Phaal, R., Farrukh, C. J. P., & Probert, D. R. (2004). Technology roadmapping—A planning framework for evolution and revolution. *Technological Forecasting and Social Change, 71*, 5–26.

Penkert, B., & Malhotra, R. (2019). *Global sportstech VC report*. Sportechx.

Penkert, B., & Malhotra, R. (2022). *Global sportstech VC report*. Sportechx.

Polaris Market Research. (2022). Racing drone market share, size, trends, industry analysis report. https://www.polarismarketresearch.com/industry-analysis/racing-drone-market. Accessed 24 Apr 2023.

Ratten, V. (2019). Sports technology and innovation. Cham: Springer Books.

Reiter, B. (2017). Theory and methodology of exploratory social science research. *International Journal of Science and Research Methodology, 5*(4), 129–150.

Research and Markets. (2022). Sports global market report. https://www.researchandmarkets.com/reports/5550013/sports-global-market-report-2022. Accessed 24 Apr 2023.

Schmidt, S. L. (2020). How technologies impact sports in the digital age. In S.L. Schmidt (Ed.), *21st Century sports. Future of business and finance* (pp. 3–14). Springer.

Schmidt, S. L. (2018). Beat the robot. https://d3.harvard.edu/beat-the-robot/. Accessed 24 Apr 2023.

Scholz, T. (2019). *ESports is business: Management in the world of competitive gaming*. Palgrave Pivot.

Standaert, W., & Jarvenpaa, S. (2016). Formula E: Next generation motorsport with next generation fans. In *International Conference on Information Systems, Dublin.*

The Guardian. (2020). World Athletics denies tipping off Nike over new running-shoe regulations. https://www.theguardian.com/sport/2020/feb/06/world-athletics-foot-down-nike-running-shoe-regulations. Accessed 13 Jan 2020.

Van Wyk, R. J. (1997). Strategic technology scanning. *Technological Forecasting and Social Change, 55*(1), 21–38.

von Hippel, E., Ogawa, S., & de Jong, J. P. J. (2011). The age of the user-innovator. *Sloan Management Review (fall), 53*(1), 27–35.

Walsh, S. T. (2003). Roadmapping a disruptive technology: A case study. *Technological Forecasting and Social Change, 71*(1–2), 161–185.

Walsh, C. J., Endo, K., & Herr, H. (2007). A quasi-passive leg exoskeleton for load-carrying augmentation. *International Journal of Humanoid Robotics, 4*, 487–506.

Weisman, L. (2014). Laser Technology enhances experience for sports fans, refs. Photonics Media, September 2014. https://www.photonics.com/Articles/Laser_Technology_Enhances_Experience_for_Sports/a56631. Accessed 19 Feb 2020.

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. In addition, he is lecturer at the Massachusetts Institute of Technology (MIT) Sports Entrepreneurship Bootcamp, a member of the Digital Initiative at Harvard Business School (HBS), and co-author of various sports-related HBS case studies. 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 an 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 the second edition of 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.

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 a 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.

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.

N. Frevel (✉) · S. L. Schmidt · D. Beiderbeck
Center for Sports and Management, WHU—Otto Beisheim School of Management, Dusseldorf, Germany
e-mail: nicolas.frevel@whu.edu

S. L. Schmidt
e-mail: sascha.schmidt@whu.edu

D. Beiderbeck
e-mail: daniel.beiderbeck@whu.edu

B. Penkert
SportsTechX GmbH, Berlin, Germany
e-mail: benjamin@sportstechx.com

B. Subirana
MIT Auto-ID lab, Massachusetts Institute of Technology, Cambridge, MA, USA
e-mail: subirana@mit.edu

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 et al., 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 et al., 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 et al. (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 al. (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 et al., 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 (Markets and Markets, 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]

---

[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/).
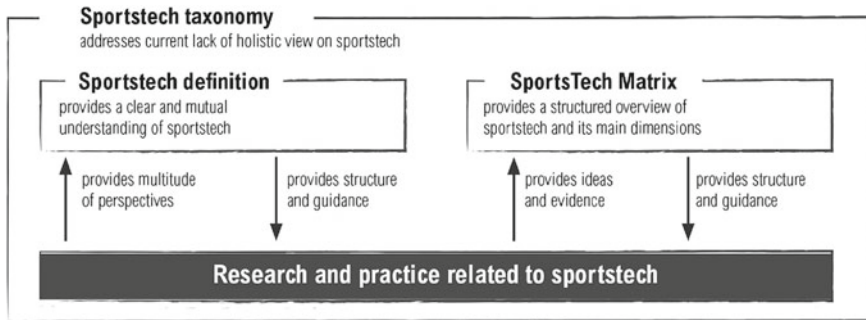
Fig. 1 Sportstech taxonomy

(cf. Ratten, 2018). However, there is a lack of overarching taxonomies, frameworks, 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 et al. 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 et al. (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

---

[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).

aims at providing a "pragmatic description of activities which could be considered as a sport" (Sportaccord, 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

---

[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 & 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).

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]

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 (Markets and Markets, 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 et al., 2017). Some examples, such as Spotify (cf. Wlömert & Papies, 2016) or Netflix (cf. Ansari et al., 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.

---

[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.

[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.

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 (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

---

[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 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).

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 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 et al., 2013; cf. Tjønndal, 2017) or comes from adjacent disciplines such as brand management (cf. Pradhan et al., 2020), biomechanics (cf. de Magalhaes et al., 2015), and ethics (cf. Evans et al., 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 et al., 2013; Dellaserra et al., 2014), machine and deep learning for sport-specific movement recognition (e.g., Cust et al., 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 et al., 2013), ubiquitous computing in sports (e.g., Baca et al., 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 et al., 2012) and data collection and processing technologies (e.g., Giblin et al., 2016).

---

[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.

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 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
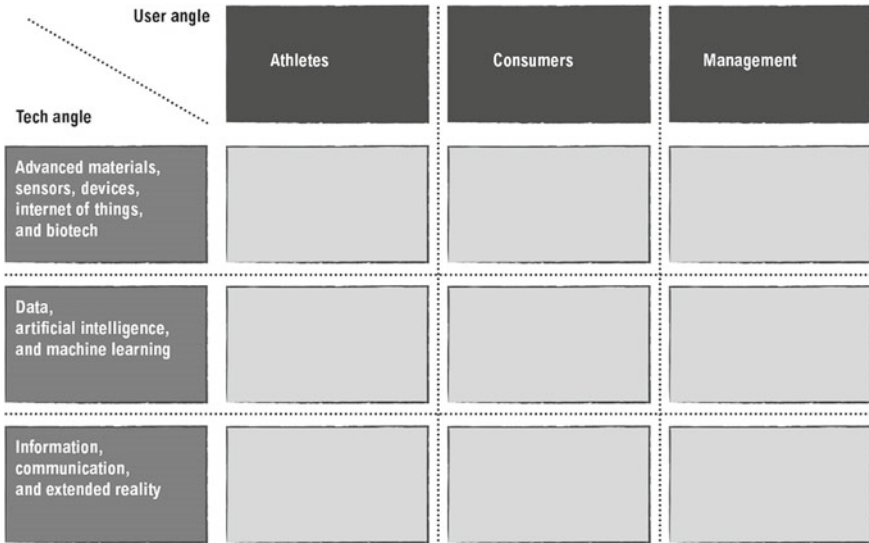
Fig. 2 SportsTech matrix

Activity & performance			Management & organisation
Wearables & equipment	**Performance tracking & coaching**	**Preparation**	**Organisations & Venues**
Wearables Game equipment Infrastructure	Activity data Video analytics Coaching	Tutorials & training Injury prevention & rehabilitation Booking & matchmarking	Team/club management Scouting & recruitment Stadium management League/tournament/event management
Fans & content			**Media & commercial partners**
News & content	**Fan experiences & social platforms**	**Fantasy sports & betting**	Media production Sponsorship Crowdfunding
News aggregator Original content OTT platforms	Fan engagement Ticketing & merchandise Social platform	Betting betting enablement Fantasy sports Fantasy sports enablement Sports games	

Fig. 3 SportsTech framework (Malhotra, 2019)

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

---

[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.

also solutions to find other players or venues and coordinate joint activities (cf. 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).

---

[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.

Existing classifications are typically limited to specific areas of technology such as information technology (cf. Fiedler et al., 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).

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.

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.

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

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 et al., 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 et al., 2017). In addition, ecosystem perspectives can be used to represent "resource flows within, in and out of a given system" (Despeisse et al., 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 et al., 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 &

---

[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).

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 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]

References

Abraham, Z. (2019). *Kevin Durant, Aaron Rogers, Serena Williams: New wave of venture capitalists.* https://oaklandnewsnow.com/2019/06/06/warriors-kevin-durant-packers-aaron-rogers-new-wave-of-venture-capitalists/. Retrieved 11 Apr 2020.

Agarwal, S., & Sanon, V. (2016). The sports technology and sports media venture ecosystem. https://www.scribd.com/document/358767732/Venture-Capital-in-Sports-Te.

Ansari, S. S., Garud, R., & Kumaraswamy, A. (2016). The disruptor's dilemma: TiVo and the U.S. television ecosystem. *Strategic Management Journal, 37*(9), 1829–1853. https://doi.org/10.1002/smj.2442.

Australian Sports Technologies Network. (2020). *Who we are.* http://astn.com.au/who-we-are/. Retrieved 16 Mar 2020.

Baca, A., Dabnichki, P., Heller, M., & Kornfeind, P. (2009). Ubiquitous computing in sports: A review and analysis. *Journal of Sports Sciences, 27*(12), 1335–1346. https://doi.org/10.1080/02640410903277427.

Bain, R. (1937). Technology and state government. *American Sociological Review, 2,* 860.

Balmer, N., Pleasence, P., & Nevill, A. (2012). Evolution and revolution: Gauging the impact of technological and technical innovation on Olympic performance. *Journal of Sports Sciences, 30*(11), 1075–1083. https://doi.org/10.1080/02640414.2011.587018.

Barris, S., & Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine, 38*(12), 1025–1043. https://doi.org/10.2165/00007256-200838120-00006.

Berthelot, G., Tafflet, M., El Helou, N., Len, S., Escolano, S., Guillaume, M., … Toussaint, J.-F. (2010). Athlete atypicity on the edge of human achievement: Performances stagnate after the last peak, in 1988. *PLoS ONE, 5*(1), e8800. https://doi.org/10.1371/journal.pone.0008800.

Berthelot, G., Thibault, V., Tafflet, M., Escolano, S., El Helou, N., Jouven, X., … Toussaint, J.-F. (2008). The citius end: World records progression announces the completion of a brief ultra-physiological quest. *PLoS ONE, 3*(2), e1552. https://doi.org/10.1371/journal.pone.0001552.

Bertram, C., & Mabbott, J. (2019). *The sportstech report—Advancing Victoria's startup ecosystem.* https://launchvic.org/files/The-SportsTech-Report.pdf.

Bloomberg. (2019). *The players technology summit*. https://www.bloomberglive.com/playerstech-2019/#row-5e9182d0336b2. Retrieved 11 Apr 2020.

Choyke, A. M., & Bartosiewicz, L. (2006). Skating with Horses: Continuity and parallelism in prehistoric Hungary. *Revue de Paléobiologie, 24*(10), 317.

Colosseum. (2019). *Sports tech report*. https://www.colosseumsport.com/wp-content/uploads/2019/08/Colosseum-Sports-Tech-Report-H1-2019-3.pdf.

Council of Europe. (2001). *Recommendation No. R (92) 13 rev of the Committee of Ministers to member States on the revised European Sports Charter*. https://rm.coe.int/16804c9dbb.

Crouse, K. (2009). *Swimming bans high-tech suits, ending an era.* https://www.nytimes.com/2009/07/25/sports/25swim.html. Retrieved 16 Apr 2020.

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: A systematic review. *Sports Medicine, 43*(10), 1025–1042. https://doi.org/10.1007/s40279-013-0069-2.

Cust, E. E., Sweeting, A. J., Ball, K., & Robertson, S. (2019). Machine and deep learning for sport-specific movement recognition: A systematic review of model development and performance. *Journal of Sports Sciences, 37*(5), 568–600. https://doi.org/10.1080/02640414.2018.1521769.

Dellaserra, C. L., Gao, Y., & Ransdell, L. (2014). Use of integrated technology in team sports. *Journal of Strength and Conditioning Research, 28*(2), 556–573. https://doi.org/10.1519/JSC.0b013e3182a952fb.

Desmet, D., Maerkedahl, N., & Shi, P. (2017). *Adopting an ecosystem view of business technology.* https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/adopting-an-ecosystem-view-of-business-technology. Retrieved 15 Mar 2020.

Despeisse, M., Ball, P. D., & Evans, S. (2013). Strategies and ecosystem view for industrial sustainability. In *Re-engineering Manufacturing for Sustainability* (pp. 565–570). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-4451-48-2_92.

Dhillon, V., Metcalf, D., & Hooper, M. (2017). *Blockchain enabled applications.* Berkeley, CA: Apress. https://doi.org/10.1007/978-1-4842-3081-7.

Dyer, B. (2015). The controversy of sports technology: A systematic review. *SpringerPlus, 4*(1). https://doi.org/10.1186/s40064-015-1331-x.

Ellis, M. E., Aguirre-urreta, M. I., Lee, K. K., Sun, W. N., Mao, J., & Marakas, G. M. (2016). Categorization of technologies: Insights from the technology acceptance literature. *Journal of Applied Business and Economics, 18*(4), 20–30.

Evans, R., McNamee, M., & Guy, O. (2017). Ethics, nanobiosensors and elite sport: The need for a new governance framework. *Science and Engineering Ethics, 23*(6), 1487–1505. https://doi.org/10.1007/s11948-016-9855-1.

Farrow, D. (2013). Practice-enhancing technology: A review of perceptual training applications in sport. *Sports Technology, 6*(4), 170–176. https://doi.org/10.1080/19346182.2013.875031.

FARSEEING. (2013). *Taxonomy of technologies.* http://farseeingresearch.eu/wp-content/uploads/2014/07/FARSEEING-Taxonomy-of-Technologies-V4.pdf.

Fiedler, K. D., Grover, V., & Teng, J. T. C. (1996). An empirically derived taxonomy of information technology structure and its relationship to organizational structure. *Journal of Management Information Systems, 13*(1), 9–34. https://doi.org/10.1080/07421222.1996.11518110.

Foster, L., James, D., & Haake, S. (2012). Influence of full body swimsuits on competitive performance. *Procedia Engineering, 34,* 712–717. https://doi.org/10.1016/j.proeng.2012.04.121.

Fuss, F. K., Subic, A., & Mehta, R. (2008). The impact of technology on sport—new frontiers. *Sports Technology, 1*(1), 1–2. https://doi.org/10.1080/19346182.2008.9648443.

Galunic, D. C., & Rodan, S. (1998). Resource recombinations in the firm: Knowledge structures and the potential for schumpeterian innovation. *Strategic Management Journal, 19*(12), 1193–1201. https://doi.org/10.1002/(SICI)1097-0266(1998120)19:12%3c1193:AID-SMJ5%3e3.0.CO;2-F.

Giblin, G., Tor, E., & Parrington, L. (2016). The impact of technology on elite sports performance. *Sensoria: A Journal of Mind, Brain & Culture*, *12*(2), 2–9. https://doi.org/10.7790/sa.v12i2.436.

Global Sports Innovation Center. (2020). *Global sports innovation center powered by Microsoft.* https://sport-gsic.com/. Retrieved 1 Apr 2020.

Goran, J., LaBerge, L., & Srinivasan, R. (2017). Culture for a digital age. *McKinsey Quarterly*, (3), 56–67. https://lediag.net/wp-content/uploads/2018/05/0-Culture-for-a-digital-age.pdf.

Guttmann, A. (1978). *From ritual to record: The nature of modern sports.* Columbia University Press.

Haake, S. J. (2009). The impact of technology on sporting performance in Olympic sports. *Journal of Sports Sciences, 27*(13), 1421–1431. https://doi.org/10.1080/02640410903062019.

Heitner, D. (2016). *A $35 million fund for sports tech and media disruptors.* https://www.forbes.com/sites/darrenheitner/2016/01/11/a-35-million-fund-for-sports-tech-and-media-disruptors/#1e578ea4168e. Retrieved 15 May 2020.

Hines, J. R. (2006). *Figure skating: A history.* University of Illinois Press.

Ho, J. C., & Lee, C. S. (2015). A typology of technological change: Technological paradigm theory with validation and generalization from case studies. *Technological Forecasting and Social Change, 97,* 128–139. https://doi.org/10.1016/j.techfore.2014.05.015.

HYPE. (2020). *Key verticals.* https://www.hypesportsinnovation.com/services/hype-spin-accelerator/. Retrieved 15 Mar 2020.

Jenny, S. E., Manning, R. D., Keiper, M. C., & Olrich, T. W. (2017). Virtual(ly) athletes: Where eSports fit within the definition of "sport". *Quest, 69*(1), 1–18. https://doi.org/10.1080/00336297.2016.1144517.

Katsarova, I., & Halleux, V. (2019). *EU sports policy: Going faster, aiming higher, reaching further.* https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/640168/EPRS_BRI(2019)640168_EN.pdf.

Khalil, T. M. (2000). *Management of technology: The key to competitiveness and wealth creation.* McGraw—Hill Book Co.

Kolbinger, O., & Lames, M. (2017). Scientific approaches to technological officiating aids in game sports. *Current Issues in Sport Science (CISS), 2*(001), 1–10. https://doi.org/10.15203/CISS_2017.001.

Lapham, A. C., & Bartlett, R. M. (1995). The use of artificial intelligence in the analysis of sports performance: A review of applications in human gait analysis and future directions for sports biomechanics. *Journal of Sports Sciences, 13*(3), 229–237. https://doi.org/10.1080/02640419508732232.

leAD. (2020). *The three verticals—What we look for.* https://www.leadsports.com/accelerator/berlin. Retrieved 15 Mar 2020.

Lemon, K. N., & Verhoef, P. C. (2016). Understanding customer experience throughout the customer journey. *Journal of Marketing, 80*(6), 69–96. https://doi.org/10.1509/jm.15.0420.

Lippi, G., Banfi, G., Favaloro, E. J., Rittweger, J., & Maffulli, N. (2008). Updates on improvement of human athletic performance: Focus on world records in athletics. *British Medical Bulletin, 87*(1), 7–15. https://doi.org/10.1093/bmb/ldn029.

Loland, S. (2009). The ethics of performance-enhancing technology in sport. *Journal of the Philosophy of Sport, 36*(2), 152–161. https://doi.org/10.1080/00948705.2009.9714754.

Lorenzo, O., Kawalek, P., & Wharton, L. (2018). *Entrepreneurship, innovation and technology: A guide to core models and tools.* Abingdon, Oxon: Routledge.

de Magalhaes, F. A., Vannozzi, G., Gatta, G., & Fantozzi, S. (2015). Wearable inertial sensors in swimming motion analysis: A systematic review. *Journal of Sports Sciences, 33*(7), 732–745. https://doi.org/10.1080/02640414.2014.962574.

Magretta, J. (2002). Why business models matter. *Harvard Business Review, 80*, 86–92.

Malhotra, R. (2019). *SportsTech framework updated.* https://medium.com/sportstechx/sportstech-framework-2019-2946533282eb. Retrieved 6 Mar 2020.

MarketsandMarkets. (2019). *Sports technology market—Global forecast to 2024.* https://www.marketsandmarkets.com/Market-Reports/sports-analytics-market-35276513.html.

Miah, A. (2006). Rethinking Enhancement in Sport. *Annals of the New York Academy of Sciences, 1093*(1), 301–320. https://doi.org/10.1196/annals.1382.020.

Miles, H. C., Pop, S. R., Watt, S. J., Lawrence, G. P., & John, N. W. (2012). A review of virtual environments for training in ball sports. *Computers & Graphics, 36*(6), 714–726. https://doi.org/10.1016/j.cag.2012.04.007.

Nevill, A. M., & Whyte, G. (2005). Are there limits to running world records? *Medicine and Science in Sports and Exercise, 37*(10), 1785–1788. https://doi.org/10.1249/01.mss.0000181676.62054.79.

Nevill, A. M., Whyte, G., Holder, R., & Peyrebrune, M. (2007). Are there limits to swimming world records? *International Journal of Sports Medicine, 28*(12), 1012–1017. https://doi.org/10.1055/s-2007-965088.

Nike. (2020). *About nike.* https://about.nike.com/.

Norman, D. A., & Verganti, R. (2014). Incremental and radical innovation: Design research vs. technology and meaning change. *Design Issues, 30*(1), 78–96. https://doi.org/10.1162/DESI_a_00250.

O'Reilly, C. A., & Tushman, M. L. (2013). Organizational ambidexterity: Past, present, and future. *Academy of Management Perspectives, 27*(4), 324–338. https://doi.org/10.5465/amp.2013.0025.

Ogus, S. (2019). *Sapphire ventures launches new $115 million venture fund centered on sports and technology.* https://www.forbes.com/sites/simonogus/2019/01/29/sapphire-ventures-launches-new-115-million-venture-centered-around-sports-and-technology/#3cd5b51d24f8. Retrieved 15 Apr 2020.

Ogus, S. (2020). *In quest for innovation, comcast NBC universal launches sports technology accelerator.* from https://www.forbes.com/sites/simonogus/2020/01/21/comcast-nbcuniversal-launches-new-sports-technology-accelerator/#44d8678b730d. Retrieved 26 Mar 2020.

Oriard, M. (2011). Rough, manly sport and the American way: Theodore Roosevelt and College Football, 1905. *Myths and milestones in the history of sport* (pp. 80–105). Palgrave Macmillan.

Penkert, B. (2017). *Framework for the #sportstech industry.* https://medium.com/sportstechx/framework-for-the-sportstech-industry-73d31a3b03bb. Retrieved 6 Mar 2020.

Penkert, B. (2019). *SportsTech framework 2019.* https://medium.com/sportstechx/sportstech-framework-2019-2b4b6fbe3216. Retrieved 6 Mar 2020.

Penkert, B., & Malhotra, R. (2019). *Global sportstech VC report 2019.* Sportechx.

Pradhan, D., Malhotra, R., & Moharana, T. R. (2020). When fan engagement with sports club brands matters in sponsorship: Influence of fan–brand personality congruence. *Journal of Brand Management, 27*(1), 77–92. https://doi.org/10.1057/s41262-019-00169-3.

Proman, M. (2019a). *Industry insights: The current state of sports technology.* https://medium.com/scrum-ventures-blog/industry-insights-the-current-state-of-sports-technology-c24506d86585. Retrieved 24 Mar 2020.

Proman, M. (2019b). *The future of sports tech: Here's where investors are placing their bets.* https://techcrunch.com/2019/10/01/the-future-of-sports-tech-heres-where-investors-are-placing-their-bets/. Retrieved 22 Mar 2020.

PwC. (2019). *Sports industry: Time to refocus? PwC's sports survey 2019.*

Ratten, V. (2016). Sport innovation management: Towards a research agenda. *Innovation, 18*(3), 238–250. https://doi.org/10.1080/14479338.2016.1244471.

Ratten, V. (2017). *Sports innovation management.* Routledge.

Ratten, V. (2018). *Sport entrepreneurship education and policy BT—Sport entrepreneurship: Developing and sustaining an entrepreneurial sports culture.* https://doi.org/10.1007/978-3-319-730 10-3_9.

Ratten, V. (2019). *Sports technology and innovation.* Springer Books.

Raveh, A., & McCumber, R. (2019). *Eight 'do or die' strategies to become a digital sports powerhouse.* https://www.sportspromedia.com/opinion/digital-strategy-golden-state-warriors-fc-koln-gen-z-fc-barcelona. Retrieved 28 Mar 2020.

Rich, P. (1992). The organizational taxonomy: Definition and design. *Academy of Management Review, 17*(4), 758–781.

Ringuet-Riot, C. J., Hahn, A., & James, D. A. (2013). A structured approach for technology innovation in sport. *Sports Technology, 6*(3), 137–149. https://doi.org/10.1080/19346182.2013.868468.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Simon and Schuster.

Rooney, K. (2020). *Why pro athletes like Richard Sherman and Andre Iguodala are cozying up to venture capital.* https://www.cnbc.com/2020/02/01/richard-sherman-kobe-bryant-and-the-athlete-to-vc-connection.html. Retrieved 11 Apr 2020.

SAP. (2020). *Sports & entertainment.* https://www.sap.com/germany/industries/sports-entertainment.html. Retrieved 8 Apr 2020.

Schumpeter, J. A. (1934). *The theory of economic development.* Harvard University Press.

Sidhu, G. (2011). *Instant replay: Investigating statistical analysis in sports.* http://arxiv.org/abs/1102.5549.

Sigrist, R., Rauter, G., Riener, R., & Wolf, P. (2013). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic Bulletin & Review, 20*(1), 21–53. https://doi.org/10.3758/s13423-012-0333-8.

Sportaccord. (2011). *Definition of sport.* https://www.sportaccord.sport/. Retrieved 16 Mar 2020.

SportsTechIreland. (2020). *SportsTech verticals.* https://sportstechireland.com/. Retrieved 15 Mar 2020.

Stefani, R. (2012). Olympic swimming gold: The suit or the swimmer in the suit? *Significance, 9*(2), 13–17. https://doi.org/10.1111/j.1740-9713.2012.00553.x.

Suits, B. (2007). The elements of sport. In W. J. Morgan (ed.), *Ethics in sport. Human kinetics* (pp. 9–19). Champaign, IL.

Tang, S. K. Y. (2008). *The rocket swimsuit: Speedo's LZR racer.* http://sitn.hms.harvard.edu/flash/2008/issue47-2/. Retrieved 11 Mar 2020.

Tjønndal, A. (2017). Sport innovation: Developing a typology. *European Journal for Sport and Society, 14*(4), 291–310. https://doi.org/10.1080/16138171.2017.1421504.

Van De Ven, A. H., & Rogers, E. M. (1988). Innovations and organizations: Critical perspectives. *Communication Research, 15*(5), 632–651. https://doi.org/10.1177/009365088015005007.

van der Kruk, E., & Reijne, M. M. (2018). Accuracy of human motion capture systems for sport applications; state-of-the-art review. *European Journal of Sport Science, 18*(6), 806–819. https://doi.org/10.1080/17461391.2018.1463397.

Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., & Haenlein, M. (2019). Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research.* https://doi.org/10.1016/j.jbusres.2019.09.022.

Virmavirta, M., & Kivekäs, J. (2019). Aerodynamics of an isolated ski jumping ski. *Sports Engineering, 22*(1), 8. https://doi.org/10.1007/s12283-019-0298-1.

Waddington, I., & Smith, A. (2000). *Sport, health and drugs: A critical sociological perspective.* Taylor & Francis.

Whipp, B. J., & Ward, S. A. (1992). Will women soon outrun men? *Nature, 325*(6355), 25.

Wlömert, N., & Papies, D. (2016). On-demand streaming services and music industry revenues— Insights from spotify's market entry. *International Journal of Research in Marketing, 33*(2), 314–327. https://doi.org/10.1016/j.ijresmar.2015.11.002.

Wylab. (2020). *Startups.* https://wylab.net/en/incubator/startups/. Retrieved 15 Mar 2020.

Zigurs, I., & Buckland, B. K. (1998). A theory of task/technology fit and group support systems effectiveness. *MIS Quarterly, 22*(3), 313. https://doi.org/10.2307/249668.

Nicolas Frevel is a Director (Digital, IT, eSport, Women's Football) and Advisor to the Executive Board at Hertha BSC. He did his Ph.D. at the Center for Sports and Management at WHU— Otto Beisheim School of Management. On the future of sports tech with the help of Delphi-based scenario analysis. Prior to his Ph.D., he worked as a consultant for McKinsey & Company. Nicolas belongs to the dying breed of "Bolzplatzkicker" and street footballers and loves to spend his time playing or watching sports with friends. His contributions to the book were inspired by his curiosity for technologies and innovation in the realm of sports.

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. In addition, he is lecturer at the Massachusetts Institute of Technology (MIT) Sports Entrepreneurship Bootcamp, a member of the Digital Initiative at Harvard Business School (HBS), and co-author of various sports-related HBS case studies. 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 an 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 the second edition of 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.

Daniel Beiderbeck is a research assistant at the Center for Sports and Management at WHU— Otto Beisheim School of Management. His research focuses on the future of sports and preparedness of (sports) organizations. Prior to starting his doctoral studies, he worked as a consultant for McKinsey & Company, Inc. where his work was centered on digital business building. Daniel holds a master's degree in industrial engineering from RWTH Aachen University and conducted his diploma thesis on additive manufacturing technologies with the Institute for Manufacturing at the University of Cambridge. Daniel recently ended his active career as amateur footballer, but still loves to play. He also tries to compete with the new generation as an amateur eGamer in his leisure time.

Benjamin Penkert is the Founder of Berlin-based SportsTechX, a market intelligence company that publishes data and insights about sportstech startups and the surrounding ecosystem. He is an expert operating at the intersection of sports and technology. Before joining the startup world, he worked as a management consultant and strategy expert in the telecommunications industry in various positions. Prior to moving to Berlin, he lived and worked in Budapest, Cologne, Malmö, and New York. In his free time, Benjamin likes to run and is always up for a game of table tennis.

Brian Subirana is the Director of the MIT Auto-ID lab, and currently teaches at Harvard University and at the MIT Bootcamps. His research centers on fundamental advances at the cross section of the internet of things (IoT) and artificial intelligence focusing on use-inspired applications in industries such as sports, retail, health, manufacturing and education. He wants to contribute to a world were spaces can have their own "brain" with which humans can converse. Before becoming an academic, he worked at the Boston Consulting Group and founded three start-ups.

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.

S. Sarma (✉)
Open Learning and Massachusetts Institute of Technology, Cambridge, MA, USA
e-mail: sesarma@mit.edu

B. Subirana
MIT Auto-ID lab, Massachusetts Institute of Technology, Cambridge, MA, USA
e-mail: subirana@mit.edu

N. Frevel
WHU—Otto Beisheim School of Management, Center for Sports and Management, Dusseldorf, Germany
e-mail: nicolas.frevel@whu.edu

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

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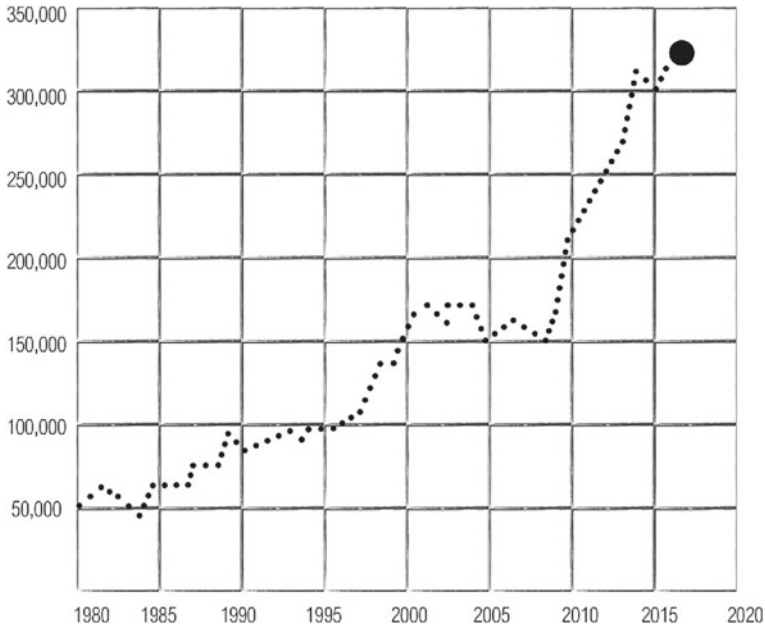
Fig. 1 USPTO utility patents issued per fiscal year (with projection for FY2017). Courtesy of dennis crouch

buy power from the grid if you can generate your own power? Why purchase a car when you 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.

---

[3] cf. Schmidt et al. (2019).

[4] Ruggiero (2017).

[5] Penkert and Malhotra (2019).

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.

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

---

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

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.

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

---

[9] Cheng (2017).

[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.

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.

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.

---

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

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.

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.

---

[14] Federal Communications Commission (FCC).

Fig. 2 Prototype of the iPod
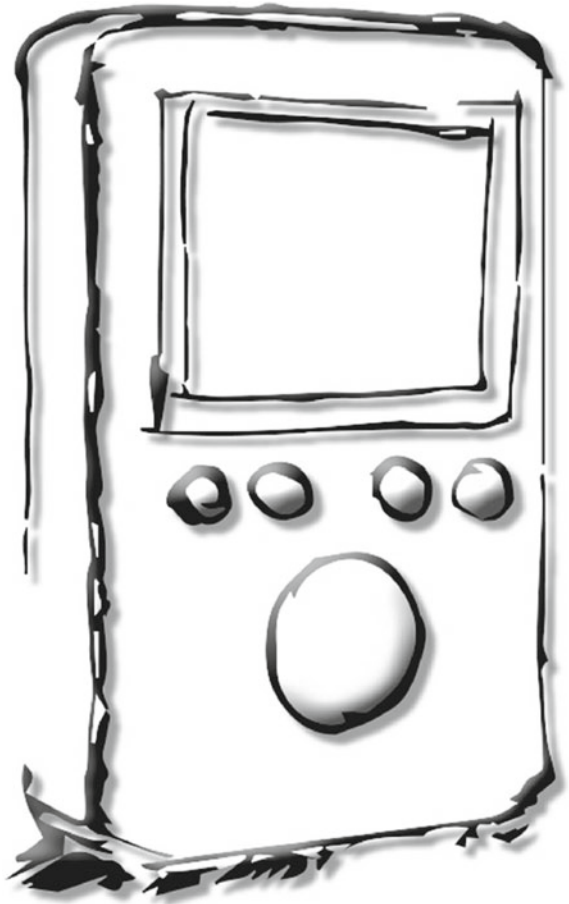
7   The Role of TDIRs in the Sports Industry

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

---

[15] PwC (2019).
[16] Schmidt et al. (2019).

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.

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.

References

Cheng, R. (2017). Netflix, will Smith bring the blockbuster home with "Bright." https://www.cnet.com/news/netflix-will-smith-bright-blockbuster-film/. Retrieved 4 Dec 2019.

DHL. (2019). Logistics trend radar. https://www.dhl.com/content/dam/dhl/global/core/documents/pdf/glo-core-trend-radar-widescreen.pdf.

Galvin, R. (1998). Science roadmaps. *Science, 280*(5365), 803–803.

Munich RE. (2018). Tech trend radar 2018. https://www.munichre.com/content/dam/munichre/global/content-pieces/documents/MunichRe-IT-Technology-Radar-2018_free_version.pdf.

Penkert, B., & Malhotra, R. (2019). *European sportstech report*. Sportechx.

PwC. (2019). *Sports industry: time to refocus?* PwC's sports survey 2019. PricewaterhouseCoopers AG.

Ruggiero, A. (2017). Disruption, innovation, and growth in the sports industry. https://www.linkedin.com/pulse/disruption-innovation-growth-sports-industry-angela-ruggiero/. Retrieved 20 Mar 2020.

Santasiere, A. (2019). Yankees magazine: The greatest lesson of all. https://www.mlb.com/news/catching-up-with-mvp-jason-giambi. Retrieved 4 Dec 2019.

Sarma, S., & Subirana B. (2018). *How to build an innovation radar. Road-mapping, news-mapping and innovation.* Auto-ID Laboratory Report No. 1. Massachusetts Institute of Technology.

Schmidt, S. L., Schreyer, D., & Krüger, H. (2019). *Future study on Bundesliga consume.* WHU.

Schmidt, S. L., Beiderbeck, D., & Frevel, N. (2019). *SPOAC Sports business study.* WHU.

Subirana, B., Sarma, S. E., Lee, R., & Dubash, J. (2005). *Peloton planning tool: Applying the peloton to the EPC industry.* GS1 EPC Global White Paper Collection.

Thuvara, V. (2006). *The Peloton Approach: Forecasting and strategic planning for emerging technologies: A case for RFID.* SM thesis, Massachusetts Institute of Technology.

Watkins, M. (2007). Demystifying strategy: The what, who, how, and why. *Harvard Business Review,* Digital Articles, 10, 2–3.

Sanjay Sarma is the Vice President for Open Learning and the Fred Fort Flowers (1941) and Daniel Fort Flowers (1941) Professor of Mechanical Engineering at MIT. A co-founder of the Auto-ID Center at MIT, Sarma developed many of the key technologies behind the EPC suite of RFID standards now used worldwide. He was also the founder and CTO of OATSystems, which

---

[17] Subirana et al. (2005).

[18] Thuvara (2006).

was acquired by Checkpoint Systems in 2008. His research includes sensors, the internet of things, cybersecurity, and RFID.

Brian Subirana is the Director of the MIT Auto-ID lab, and currently teaches at Harvard University and at the MIT Bootcamps. His research centers on fundamental advances at the cross section of the internet of things (IoT) and artificial intelligence focusing on use-inspired applications in industries such as sports, retail, health, manufacturing and education. He wants to contribute to a world were spaces can have their own "brain" with which humans can converse. Before becoming an academic, he worked at the Boston Consulting Group and founded three start-ups.

Nicolas Frevel is a Ph.D. student at the Center for Sports and Management (CSM) at WHU—Otto Beisheim School of Management. He conducts research on the future of sports with the help of Delphi-based scenario analysis. His focus is on technologies in sport. He is also a consultant at McKinsey & Company. Nicolas belongs to the dying breed of "Bolzplatzkicker" and street footballers and loves to spend his time playing or watching sports with friends. His contributions to the book were inspired by his curiosity for technologies and innovation in the realm of sports.

How to Predict the Future of Sports

Sascha L. Schmidt, Daniel Beiderbeck,
and Heiko A. von der Gracht

Abstract

Schmidt, Beiderbeck, and von der Gracht start with a pair of intriguing questions: Is it possible to predict the future of sports in this digital age? And, if so, what scientific methods can be used to forecast the impact of technology on the field? To answer, they first weigh the benefits and drawbacks of popular quantitative and qualitative forecasting techniques before outlining the Delphi method in some depth. They provide empirical results from a number of future studies in sports, concluding that with the right objective and participants, it is possible to predict the future.

1 Foresight in Theory and Practice

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). Today, forecasting is the process of making predictions about the future based on historical and present data—most commonly by using trend, indicator,

S. L. Schmidt (✉) · D. Beiderbeck
Center for Sports and Management, WHU—Otto Beisheim School of Management, Vallendar,
Germany
e-mail: sascha.schmidt@whu.edu

D. Beiderbeck
e-mail: daniel.beiderbeck@whu.edu

H. A. von der Gracht
KPMG and Steinbeis School of International Business and Entrepreneurship, Herrenberg,
Germany
e-mail: vondergracht@steinbeis-sibe.de

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 futures analysis and used to predict future data as a function of past data. They are appropriate when sufficient historical data is available and when some of the patterns in the data are expected to continue (Rescher, 1998).

The crux, however, is that in disruptive times, interpolating historical data no longer allows for valid assumptions and scenarios for the future. Since our world might change even more radically in the coming decade 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. Against this backdrop—and if we cross the bridge to the sports industry—the question of how athletes, fans, and managers deal with new technologies in their professional and private environments remains uncertain and ambiguous. To assess emerging technologies and their future impact, research typically builds on the personal judgment and intuition of true subject matter experts with long-standing experience. This kind of technique is usually applied to intermediate- and long-range scenarios and is appropriate when past data are not available or disruptive development is foreseeable (Archer, 1980); it is often referred to as qualitative forecasting.

While forecasting has its merits, it's just one piece of the larger puzzle that is strategic foresight. By adopting a systematic approach to exploring potential future scenarios, organizations can gain valuable insights into emerging trends, risks, and opportunities. And with a variety of foresight strategies at our disposal, we can employ a range of techniques to paint a picture of what the future might hold, even in the face of uncertainty. After all, the presence of uncertainty should only motivate decision-makers to use the best possible tools to craft a vision of what lies ahead.

When it comes to putting foresight into action, there's a whole array of methods at your disposal. And as the old saying goes, the more the merrier! While some methods are more comprehensive than others, it's always wise to bring multiple perspectives to the table. Figure 1 showcases an approach to categorize qualitative, quantitative, and semi-quantitative methods that can then be used in a variety of settings and combinations. Many of them can also be assisted by software usage and are part of so-called foresight support systems (von der Gracht et al, 2015). Guided by the specific purpose and context of the foresight endeavor, practitioners can choose from the rich set of tools and techniques. There's no one-size-fits-all approach as each method has its own unique strengths and weaknesses. Ultimately, the quality of empirical results will depend on how rigorously the procedures are followed. For example, when using the Delphi expert survey methodology, two of the most critical success factors are selecting the right experts and formulating strong future projections (also known as "theses"). Unfortunately, many of the studies available fail to achieve the standards.

Attempting to present and describe in detail all of the existing methods would be a monumental task, as each method could fill entire books with information.
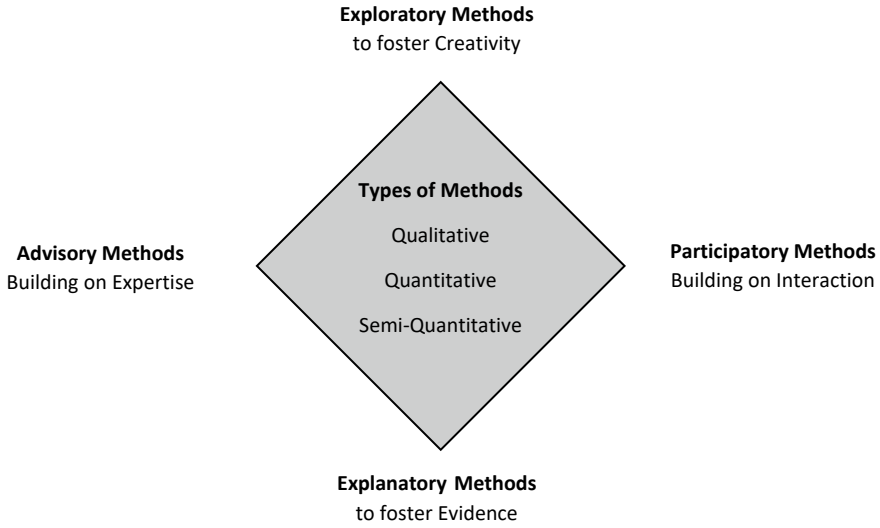
Fig. 1 Categorization of foresight methods (based on Propper 2008a, 2008b, 2011)

Therefore, we offer a concise and helpful summary (with a slight focus on more creative future-oriented methods) to give you a taste of what's out there. For a more detailed description of all techniques, readers can refer to the original references of this foresight diamond (Popper, 2008a, 2008b, 2011):

- One of the most vital and exciting tools of foresight management is the **scenario technique** (*exploratory*). This method provides a structured approach for thoroughly describing and analyzing potential future scenarios (as highlighted by Bradfield et al, 2005). When crafting scenarios, it's crucial to maintain plausibility and consistency in your assumptions and narrative plots. This method is especially effective when tackling complex situations, as it considers numerous influencing factors and their interactions. The beauty of scenario planning is that you can look back from the future, crafting scenarios that read as if they were written after the events unfolded.
- **Wildcard analyses** (*exploratory*) examine the surprising future. Wildcards describe low-probability, high-impact events and developments that can be considered dramatic game-changers should they occur. Wildcard analyses should complement scenario planning and act as a stress test or sensitivity analysis. In the iKnow research project, for example, the European Commission has built up a database of 30,058 wildcards (as of May 2022) (publicly available: http://wiwe.iknowfutures.org) (iKnow Project team, 2022).
- **Science Fiction Prototyping** (*exploratory)* was first introduced by Brian David Johnson in 2010 as a systematic procedure (called "future casting") during his time at semiconductor manufacturer Intel. This method employs science fiction

to explore market needs for specialized integrated circuits at the end of their seven- to ten-year development cycle (Johnson, 2011).

- **Backcasting** (*exploratory/advisory*) is a method to analyze the paths towards the future. The method was developed in the 1970s in climate research (Lovins, 1977). It involves plotting important decision points from a future scenario (usually a desirable one) backward while taking different stakeholders into account.
- **Roadmapping** (*exploratory/advisory*) is the opposite of backcasting and involves examining several potential pathways that lead toward a future scenario (Daim et al, 2014). This forward-looking method is often used in the context of product, innovation, technology, R&D, or industry roadmaps, and can be combined with other techniques such as scenario analysis, Delphi surveys, or patent analyses, depending on the specific context. The goal of roadmapping is to create a visual roadmap that can help organizations and decision-makers better navigate the path to their desired future (Phaal et al., 2004; Walsh, 2003).
- **The Delphi method** (*advisory/participatory*) was developed in the 1950s by the RAND Corporation, initially for military use (Dalkey & Helmer, 1963). In the 1960s, however, it quickly found its way into research and corporate practice. The method describes a multi-round survey process wherein a group of designated experts evaluates future theses (i.e., projections) and supports their assessments with arguments. Usually, the probability of occurrence, impact, and desirability are assessed. The written survey is anonymous, and participants have the opportunity to revise their own assessments based on the group's opinion and argument feedback (Beiderbeck et al., 2021a, 2021b).
- **Cross-Impact Analysis** (*explanatory/advisory*) was created by Theodore J. Gordon and Olaf Helmer in 1966. Originally, it was used as part of a card and dice game called "Future" for the Kaiser Aluminum and Chemical Company (Gordon & Hayward, 1968). The method is useful for evaluating and calculating the effects of interactions between various factors, trends, or developments, and can help identify both active and passive factors. It is often used in conjunction with scenario planning and Delphi research.
- **Benchmarking** (*participatory/explanatory*) is a well-known technique in business studies and corporate contexts. Data among a group of peers is collected to facilitate comparison, identification of best practices, and gap analyses. However, benchmarking can also be extended to the foresight context in order to measure and improve organizational future-readiness or preparedness (Meyer et al., 2020; Rohrbeck & Kum, 2018).

Based on our experience, most organizations use only four to five of the more than 40 available planning methods. This means there's a lot of untapped potential. Professionalization offers the opportunity to plan more robustly for the future, better identify opportunities, and manage risks. By combining different planning methods, organizational leaders can broaden their perspectives and improve their decision-making process. In turn, the validity of their decisions increases.

2 Foresight in Sports Today

Strategic foresight methods are essential when it comes to anticipating future developments in sports. This is particularly important because, by nature, the sports industry has always been a disruptive environment. In the past, we have witnessed significant disruptions, such as the introduction of the Fosbury-Flop in high jumping. Today, we continue to see disruptions, particularly with the introduction of entirely new sports—either as a variation of existing disciplines (for example, *padel* as a variation of tennis and squash) or as a result of technological advancements (such as *drone racing*, an entirely new type of competition).

There is growing interest in anticipating the outcomes of sporting events. Betting companies have been working on this topic for many years; but with the emergence of machine learning, new options for simulating and forecasting competition results have become available. For instance, Schlembach et al. (2022) used a random forest algorithm to predict the distribution of Olympic medals based on several variables. Their study demonstrated that a smart algorithm can outperform naïve models, which is promising news for a wider audience beyond the scope of track and field. While there are many more examples, we won't delve deeper into the topic of result prediction. However, it's certain that several areas of application will advance in the future. Therefore, a dedicated foresight study on this complex field of work could be of interest to a variety of stakeholders.

As in many other industries, the advancement of technology has led to a significant increase in the frequency of disruption in sports. One reason for this is the social relevance of the entire sector. The public has had a high interest in sports for centuries and, due to its broad reach across all social classes, the sports industry is a perfect testing ground for spreading innovations. However, most essential innovations are revolutionary rather than evolutionary. Therefore, they are harder to predict using typical quantitative foresight methods. In other words, to get an idea of potential future developments in sports, you need to combine expertise and creativity. A simple extrapolation of past developments will not help to create comprehensive future scenarios.

As mentioned above, one empirical method to facilitate qualitative/subjective foresight in sports is the Delphi method. While the technique earned its name from the aforementioned Oracle of Delphi, it has little to do with supernational visions of the future; instead, it describes a structured process in which subject matter experts try to form a consolidated view of future developments in a specific area. In a typical research setting, experts would assess a variety of future-oriented projections in terms of their respective expected probability as well as their desirability and impact in case of occurrence. Importantly, all these assessments are anonymous, which allows participants to share their opinions without restraint; this can be particularly valuable if they hold an unpopular opinion or their perspectives are not fully aligned with their employers. It also avoids typical group thinking problems like the orientation toward people that are higher in the hierarchy or other biases that can occur due to the power and opinion imbalance within a group. By quantifying the experts' assessments and feeding intermediate results

back to the panel, the technique also triggers an iterative process that leads to either consensus or dissent among experts. The method administrator can then infer different future scenarios from the quantitative results supported by the participants' qualitative comments.

The Delphi method is not intended to precisely predict the future, as with all prospective studies. Its purpose is to provide an analytical foundation for participants to engage in discourse and discuss potential developments. This allows stakeholders to collectively generate future scenarios and gain what we call "experience substitution." When facing uncertainty and disruption, it's difficult to rely on experience because disruptive situations typically present new challenges. However, experience substitution provides a bit more confidence on a specific subject because several subject matter experts have thought through potential future disruptions and shared their views. Stakeholders can then build their own action plans based on what they learned from the Delphi results and their own thoughts during the participation process.

We have conducted several Delphi studies in various domains, ranging from the sports industry as a whole (e.g., the impact of technology on sports management and development of sports sponsoring) and distinct sports (e.g., future of association football, evolution of winter sports, and emergence of eSports racing) to uniquely disruptive situations (e.g., the COVID-19 pandemic and its impact on sports). While we won't delve into the details of each study, we encourage researchers, subject matter experts, and decision-makers to utilize this tool, either as an operator or participant, because we strongly believe in its power. Below, we highlight a few of the uses and benefits that Delphi studies can offer.

The Delphi method can serve its administrators in three ways: (1) It can produce a unified view of future developments from a large group of stakeholders. In this application, there is potential for a political dimension because you want to involve *all* relevant stakeholders, which is sometimes difficult in international sports settings. (2) It can glean inspiration, advice, or perspective from participants outside of your organization. In this application, outsiders are given the opportunity and anonymity to share their thoughts and expertise (3) It can create a tangible vision for future scenarios that are focused on the mid- to long-term. While you can put all three aspects into one study, most administrators focus on one or two of the mentioned goals per Delphi project.

To provide concrete examples of the possible outputs of a Delphi study, we discuss three academic articles in the field of professional football. These examples showcase the potential of Delphi projects.

(1) **Governing body view**: A recent study conducted in collaboration with FIFA investigated the influence of technology on association football (Beiderbeck et al., 2023). It provided an unprecedented and holistic view from over 80 technical directors representing all official FIFA confederations. As expected, the study confirmed that officials perceive benefits in technology for game-related processes, such as intelligent training equipment, on-field and

off-field communication, and real-time analysis. Interestingly, most participating member associations expressed reservations regarding technology affecting game-related capacities, such as immediate coaching decisions or AI-based tactics. However, smaller and less developed associations were more desirous for technology to spread within the industry. The study revealed that technology generally makes football fairer, and that technology and data science are the fastest growing areas in football clubs and federations. This comprehensive, international perspective on technology in football underpinned FIFA's mandate to exploit the current benefits of technology and explore future potentials of technology in football on all levels around the globe.

(2) **Industry perspective**: During the COVID-19 pandemic, decision-makers in the football industry faced an unprecedented situation as football was one of the first industries to come to a full stop. But, it was also among the first to pioneer new ways of operating with remote training, closed-door competitions, and, later the gradual return of spectators. In this unique period, Beiderbeck et al. (2021a) conducted a Delphi study with 110 subject matter experts to assess the pandemic's impact on the regulatory, economic, social, and technological aspects of football. The analysis provided valuable insight into the industry, offering guidance to navigate through uncertain times. Looking back, the experts' projections turned out to be quite accurate, indicating that Delphi-based industry perspectives can be a reliable tool for decision-makers during disruptive times. Their projections correctly showed the rebound in player transfer spending, the impact of the pandemic but recovering trend in sponsorship and broadcasting revenues, and the impact on post-pandemic economic issues.

(3) **Future Reality**: In 2016, Schmidt, Merkel, and Schreyer published an insightful Delphi study that explored the landscape of professional football in the year 2025. The study relied on expert insights to explore how the industry would change over a 10-year period, considering various aspects such as the game itself, its consumption, and its commercialization. The study accurately predicted some "desirable" developments that are now considered commonplace such as clubs taking on social responsibility, the emergence of digital sponsorship revenue, and the "second screen" that many viewers use to supplement their sports consumption with additional data information or interaction with social media. However, the Delphi study also highlighted some outcomes that were not desirable like fans' increased identification with superstars over clubs. Although experts considered this outcome less desirable, it has become a reality to some extent. Despite being rated as the least probable projection, the idea that economic criteria and brand popularity would decide the clubs participating in the UEFA Champions League was proven possible with the Super League controversy in 2021. Overall, this Delphi study defined a possible future for football and provided a platform to think through other potential developments. To make it more engaging, the study results were captured in an animated video, which can be a helpful tool to create a tangible future vision.

An additional benefit of the Delphi study afforded to its practitioners is an insight into different sub-groups of study participants. A noteworthy example of this is the significant difference in future assessments based on the level of optimism exhibited by participants. This shows that personality traits play a crucial role in shaping how individuals envision the future. While this sounds intuitive, it's important to keep this in mind when thinking about future developments, especially with experts you don't know that well.

3   Future Trajectories of Foresight in Sports

Over the past decade, we've seen an increase in Delphi studies within the sports industry. However, there is still much potential for future applications, both in academia and practice. Future research and scenario building could focus on topics such as (1) the digital transformation of the sports industry (e.g., the impact of artificial intelligence, metaverse, and virtual reality), (2) the technification of sports through e.g., the impact of robotics, real-time filming and interpretation, or the impact of 3D-printing (Frevel et al. 2022), (3) the revolution of sports consumption (e.g., revolution of stadium experience, broadcasting, and fan interaction), and (4) the evolution of the general sports environment (e.g., evolution of sports regulations, disciplines, and sports financing). Industry experts, scientists, and managers all over the world are already dealing with these topics. The Delphi method could be a valuable tool to bring together this scattered knowledge and creativity to anticipate future developments. Exploring these topics will generate new ideas and perspectives, create potential scenarios, and be a fun and inspirational experience for all involved.

References

Archer, B. H. (1980). Forecasting demand: Quantitative and intuitive techniques. *International Journal of Tourism Management, 1*(1), 5–12.

Armstrong, J. S. (Ed.). (2001). *Principles of forecasting: A Handbook for researchers and practitioners.* Kluwer Academic Publishers.

Beiderbeck, D., Evans, N., Frevel, N., & Schmidt, S. L. (2023). The impact of technology on the future of football—A global Delphi study. *Technological Forecasting and Social Change, 187*, 122186.

Beiderbeck, D., Frevel, N., von der Gracht, H. A., Schmidt, S. L., & Schweitzer, V. M. (2021a). Preparing, conducting, and analyzing Delphi surveys: Cross-disciplinary practices, new directions, and advancements. *MethodsX, 8*, 101401.

Beiderbeck, D., Frevel, N., von der Gracht, H. A., Schmidt, S. L., & Schweitzer, V. M. (2021b). The impact of COVID-19 on the European football ecosystem—A Delphi-based scenario analysis. *Technological Forecasting and Social Change, 165*, 120577.

Bradfield, R., Wright, G., Burt, G., Cairns, G., & Van Der Heijden, K. (2005). The origins and evolution of scenario techniques in long range business planning. *Futures, 37*(8), 795–812.

Daim, T. U., Pizarro, M., & Talla, R. (Eds.). (2014). *Planning and roadmapping technological innovations: Cases and tools.* Springer International Publishing Switzerland.

Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. *Management Science, 9*(3), 458–467.

Frevel, N., Beiderbeck, D., & Schmidt, S. L. (2022). The impact of technology on sports—A prospective study. *Technological Forecasting and Social Change, 182*, 121838.

Gordon, T. J., & Hayward, H. (1968). Initial experiments with the cross impact matrix method of forecasting. *Futures, 1*(2), 100–116.

Häder, M. (2009). *2800 Jahre Delphi: Ein historischer Überblick*. VS Verlag für Sozialwissenschaften.

Johnson, B. D. (2011). Science fiction prototyping: Designing the future with science fiction. *Synthesis Lectures on Computer Science, 3*(1), 1–190.

iKnow Project team. (2022). *Welcome to iKnow: The innovation, foresight and horizon scanning system*. http://wiwe.iknowfutures.org/

Lovins, A. B. (1977). *Soft energy paths: Toward a durable peace*. Friends of the earth international.

Meyer, T., von der Gracht, H. A., & Hartmann, E. (2020). How organizations prepare for the future: A comparative study of firm size and industry. *IEEE Transactions on Engineering Management, 69*(2), 511–523.

Phaal, R., Farrukh, C. J. P., & Probert, D. R. (2004). Technology roadmapping—A planning framework for evolution and revolution. *Technological Forecasting and Social Change, 71*, 5–26.

Popper, R. (2008a). Foresight methodology. In L. Georghiou, J. Cassingena, M. Keenan, I. Miles, & R. Popper (Eds.), *The handbook of technology foresight: Concepts and practice* (pp. 44–88). Edward Elgar.

Popper, R. (2008b). How are foresight methods selected? *Foresight—the Journal of Future Studies, Strategic Thinking and Policy, 10*(6), 62–89.

Popper, R. (2011). *About futures diamond: The Framework*. www.futuresdiamond.com/the-diamond

Rescher, N. (1998). *Predicting the future: An introduction to the theory of forecasting*. State University of New York Press.

Rohrbeck, R., & Kum, M. E. (2018). Corporate foresight and its impact on firm performance: A longitudinal analysis. *Technological Forecasting and Social Change, 129*, 105–116.

Schlembach, C., Schmidt, S. L., Schreyer, D., & Wunderlich, L. (2022). Forecasting the Olympic medal distribution—A socioeconomic machine learning model. *Technological Forecasting and Social Change, 175*, 121314.

Von der Gracht, H. A., Bañuls, V. A., Turoff, M., Skulimowski, A. M., & Gordon, T. J. (2015). Foresight support systems: The future role of ICT for foresight. *Technological Forecasting and Social Change, 97*, 1–6.

Walsh, S. T. (2003). Roadmapping a disruptive technology: A case study. *Technological Forecasting and Social Change, 71*(1–2), 161–185.

Sascha L. Schmidt is the Director of the Center for Sports and Management and Professor of Sports and Management at WHU—Otto Beisheim School of Management in Dusseldorf. In addition, he is lecturer at the Massachusetts Institute of Technology (MIT) Sports Entrepreneurship Bootcamp, a member of the Digital Initiative at Harvard Business School (HBS), and co-author of various sports-related HBS case studies. 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 an 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 the second edition of 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.

D. Beiderbeck is Head of Projects and Development Sport at Borussia Dortmund (BVB). He has a Ph.D. from WHU—Otto Beisheim School of Management, Center for Sports and Management, in Germany, and is still affiliated with the research team at the center. His research interests lie in technology foresight in the context of football and leadership in times of uncertainty. He graduated from RWTH Aachen University and holds a Master of Science in Industrial Engineering. His work has been published in books, the Centre for Technology Management Working Paper Series at Cambridge University, as well as journals such as Technological Forecasting & Social Change, and MethodsX. Before stepping into academia and business, Daniel was an ambitious football player at SV Rödinghausen. Despite some talent, he trusted his foresight capabilities in his early years and decided to focus more on his career off the pitch than on the pitch—but surely never lost his passion for the sport.

H. A. von der Gracht is a Professor of Futures Studies and Foresight at Steinbeis University, School of International Business and Entrepreneurship (SIBE), Germany. Since 2013, he has also held various management positions at KPMG Germany and is the current Department Head in KPMG's Solutions unit and Head of the firm's cross-divisional Metaverse Taskforce. He has published more than 100 scientific and practice-oriented articles and has given more than 250 conference appearances and lectures. He is the founder and co-editor of several academic journals. Since 2017, he has served as an Associate Editor of *Technological Forecasting & Social Change*. He is a big fan of TTC Jülich, an enthusiastic table tennis player, and an active skier.

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.

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.

J. Siegel (✉)
Computer Science and Engineering, Michigan State University, East Lansing, MI, USA
e-mail: jsiegel@msu.edu

D. Morris
Electrical and Computer Engineering, Michigan State University, East Lansing, MI, USA
e-mail: dmorris@egr.msu.edu

Athletes may excel in strength, endurance, quick reactions, precise control, or strategic planning. Common traits include competitiveness and a desire to out-smart, 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 & 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 Turtle-Bot (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 (Kaminaga et al., 2017; Kuindersma et al., 2016; Salerno et al., 2016; Suzumori & Faudzi, 2018) and biomimetic muscles (Lee et al., 2017; Must et al., 2015) 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 (Onose et al., 2016; The Star Online, 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 & Perkis, 2018) or 360° recording (Standaert & 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, (Hamari & Sjöblom, 2017; Llorens, 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 & 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 (Kohler, 2016; Yasumoto, 2015), 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 & Londt, 2010) include the STEM-focused FIRST competition and its feeder series, the Robofest competition, (Chung & Cartwright, 2011; Chung et al., 2014) 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 (Buehler et al., 2007, 2009; Guizzo & Ackerman, 2015; Kopacek, 2009; Thrun et al., 2006) and the DARPA Robotics Challenge (Guizzo & Ackerman, 2015). More subtly technical sports include automated small-scale car racing (Karaman et al., 2017; O'Kelly et al., 2019; Roscoe, 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, 2016b, 2016c, 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, 2018c) 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 (Brackett, 2017; Ross, 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 & 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.

References

Abadi, M., Agarwal, A., Barham, P., Brevdo, E., Chen, Z., Citro, C., et al. (2016). TensorFlow: Large-scale machine learning on heterogeneous distributed systems. White Paper. Retrieved from http://download.tensorflow.org/paper/whitepaper2015.pdf

Armengol Urpi, A. (2018). *Responsive IoT: Using biosignals to connect humans and smart devices.* Doctoral thesis. Massachusetts Institute of Technology, Department of Mechanical Engineering.

Blackstock, E. (2018). Formula E won't have to swap cars mid-race next season. Jalopnik, 31 March 2018. Retrieved October 2, 2019, from https://jalopnik.com/formula-e-wont-have-to-swap-cars-next-season-1824228506

Brackett, E. (2017). Yamaha shows off the improved Motobot at Tokyo Motor Show 2017, DigitalTrends, 29 October 2017. Retrieved October 2, 2019, from https://www.digitaltrends.com/cars/yamaha-shows-off-new-motobot/

Buehler, M., Iagnemma, K., & Singh, S. (2007). *The 2005 DARPA grand challenge: The great robot race* (Vol. 36). Springer.

Buehler, M., Iagnemma, K., & Singh, S. (2009). *The DARPA urban challenge: Autonomous vehicles in city traffic* (Vol. 56). Springer.

Burkhard, H. D., Duhaut, D., Fujita, M., Lima, P., Murphy, R., & Rojas, R. (2002). The road to RoboCup 2050. *IEEE Robotics Automation Magazine, 9*(6), 31–38.

Calkins, D. (2011). An overview of robogames [competitions]. *IEEE Robotics and Automation Magazine, 18,* 14–15.

Campbell, M., Hoane, A. J., & Hsu, F.-H. (2002). Deep blue. *Artificial Intelligence, 134,* 57–83.

Chen, J. (2018). *Towards automatic broadcast of team sports.* Doctoral thesis. The University of British Columbia.

Chung, C. J., & Cartwright, C. (2011). Evaluating the long-term impact of robofest since 1999. Retrieved October 2, 2019, from https://www.robofest.net/2011/ARISE-TM-2011-3.pdf

Chung, C. J. C., Cartwright, C., & Cole, M. (2014). Assessing the impact of an autonomous robotics competition for STEM education. *Journal of STEM Education: Innovations and Research, 15,* 24.

Ciuti, G., Ricotti, L., Menciassi, A., & Dario, P. (2015). MEMS sensor technologies for human centred applications in healthcare, physical activities, safety and environmental sensing: A review on research activities in Italy. *Sensors, 15,* 6441–6468.

Delbruck, T., Pfeiffer, M., Juston, R., Orchard, G., Müggler, E., Linares-Barranco, A., & Tilden, M. W. (2015). Human versus computer slot car racing using an event and frame-based DAVIS vision sensor. In *2015 IEEE International Symposium on Circuits and Systems (ISCAS).*

Edelstein, S. (2019). The technologies your car inherited from race cars, DigitalTrends, 9 June 2019. Retrieved October 2, 2019, from https://www.digitaltrends.com/cars/racing-tech-in-your-current-car/

Frias, F. J. L., & Triviño, J. L. P. (2016). Will robots ever play sports? *Sport, Ethics and Philosophy, 10*, 67–82.

Gaudiosi, J. (2016). The super bowl of drone racing will offer $1 million in prize money, Fortune, 3 March 2016. Retrieved October 2, 2019, from https://fortune.com/2016/03/03/world-drone-prix-offers-1-million-prize-money/

Gerndt, R., Seifert, D., Baltes, J. H., Sadeghnejad, S., & Behnke, S. (2015). Humanoid robots in soccer: Robots versus humans in RoboCup 2050. *IEEE Robotics and Automation Magazine, 22,* 147–154.

Guizzo, E., & Ackerman, E. (2015). The hard lessons of DARPA's robotics challenge [News]. *IEEE Spectrum, 52,* 11–13.

Hagras, H. (2018). Toward human-understandable, explainable AI. *Computer, 51*(9), 28–36.

Hamari, J., & Sjöblom, M. (2017). What is eSports and why do people watch it? *Internet Research, 27*(2), 211–232.

Hameed, A., & Perkis, A. (2018). Spatial storytelling: Finding interdisciplinary immersion. In *International Conference on Interactive Digital Storytelling.*

Indy Autonomous Challenge. (2019). Retrieved November 6, 2019, from https://www.indyautonomouschallenge.com/

Johnson, R. T., & Londt, S. E. (2010). Robotics competitions: The choice is up to you! *Tech Directions, 69,* 16.

Kaminaga, H., Ko, T., Masumura, R., Komagata, M., Sato, S., Yorita, S., & Nakamura, Y. (2017). Mechanism and control of whole-body electro-hydrostatic actuator driven humanoid robot hydra. In *2016 International Symposium on Experimental Robotics.*

Kanaan, T. (2015). Why we race, The Players' Tribune, 8 September 2015. Retrieved October 2, 2019, from https://www.theplayerstribune.com/en-us/articles/tony-kanaan-justin-wilson-ind ycar

Karaman, S., Anders, A., Boulet, M., Connor, J., Gregson, K., Guerra, W., et al. (2017). Project-based, collaborative, algorithmic robotics for high school students: Programming self-driving race cars at MIT. In *2017 IEEE Integrated STEM Education Conference (ISEC)*.

Kitano, H., Asada, M., Kuniyoshi, Y., Noda, I., & Osawa, E. (1995). *Robocup: The robot world cup initiative.* IJCAI-95 Workshop on entertainment and AI/Alife.

Kohler, J. (2016). The sky is the limit: FAA regulations and the future of drones. *Colorado Technology Law Journal, 15,* 151.

Kondratenko, Y. P. (2015). Robotics, automation and information systems: Future perspectives and correlation with culture, sport and life science. In *Decision Making and Knowledge Decision Support Systems* (pp. 43–55). Springer.

Kopacek, P. (2009). Automation in sports and entertainment. In S. Y. Nof (Ed.) *Springer handbook of automation* (pp. 1313–1331). Springer.

Kuindersma, S., Deits, R., Fallon, M., Valenzuela, A., Dai, H., Permenter, F., et al. (2016). Optimization-based locomotion planning, estimation, and control design for the atlas humanoid robot. *Autonomous Robots, 40*(3), 429–455.

Lee, C., Kim, M., Kim, Y. J., Hong, N., Ryu, S., Kim, H. J., & Kim, S. (2017). Soft robot review. *International Journal of Control, Automation and Systems, 15*(1), 3–15.

Llorens, M. R. (2017). eSport gaming: The rise of a new sports practice. *Sports, Ethics and Philosophy, 11*(4), 464–476.

Martins, F. N., Gomes, I. S., & Santos, C. R. F. (2015). Junior soccer simulation: Providing all primary and secondary students access to educational robotics. In *2015 12th Latin American Robotics Symposium and 2015 3rd Brazilian Symposium on Robotics (LARS-SBR)*.

Munn, J. S. (2016). *Using an aerial drone to examine lateral movement in sweep rowers.* Electronic Thesis and Dissertation Repository. 4059. The University of Western Ontario.

Must, I., Kaasik, F., Poldsalu, I., Mihkels, L., Johanson, U., Punning, A., & Aabloo, A. (2015). Ionic and capacitive artificial muscle for biomimetic soft robotics. *Advanced Engineering Materials, 17*, 84–94.

Nagata, M. (2019). Basketball robot Cue3 and B. League's Alvark Tokyo join Olympic effort to teach students math, Japan Times. Retrieved October 2, 2019, from https://www.japantimes. co.jp/news/2019/06/28/business/tech/basketball-robot-cue3-b-leagues-alvark-tokyo-join-oly mpic-effort-teach-students-math/

Nardi, D., Roberts, J., Veloso, M., & Fletcher, L. (2016). Robotics competitions and challenges. In B. Siciliano & O. Khatib (Eds.), *Springer handbook of robotics* (pp. 1759–1788). Springer International Publishing.

O'Kelly, M., Sukhil, V., Abbas, H., Harkins, J., Kao, C., Pant, R. V., et al. (2019). F1/10: An open-source autonomous cyber-physical platform.

O'Leary, M. B. (2016). Pushing the limits of athletic performance, MIT News. Retrieved October 2, 2019, from http://news.mit.edu/2017/mit-3-sigma-sports-engineering-0717

Onose, G., Cârdei, V., Crăciunoiu, Ş. T., Avramescu, V., Opriş, I., Lebedev, M. A., et al. (2016). Mechatronic wearable exoskeletons for bionic bipedal standing and walking: A new synthetic approach. *Frontiers in Neuroscience, 10,* 343.

Ossmy, O., Hoch, J. E., MacAlpine, P., Hasan, S., Stone, P., & Adolph, K. E. (2018). Variety wins: Soccer-playing robots and infant walking. *Frontiers in Neurorobotics, 12,* 19.

Paszke, A., Gross, S., Chintala, S., Chanan, G., Yang, E., DeVito, Z., et al. (2017). Automatic differentiation in pytorch. In *31st Conference on Neural Information Processing Systems (NIPS 2017)*.

Pyo, Y., Cho, H., Jung, L., & Lim, D. (2015). *ROS robot programming.* ROBOTIS Co.

Quigley, M., Conley, K., Gerkey, B., Faust, J., Foote, T., Leibs, J., et al. (2009). ROS: An open-source robot operating system. In *ICRA Workshop on Open Source Software*.

RoboGames. (2017). Results from Robogames 2017, RoboGames. Retrieved October 2, 2019, from http://robogames.net/2017.php

Roscoe, W. (2019). Donkey car: An opensource DIY self driving platform for small scale cars. Retrieved October 2, 2019, from http://donkeycar.com

Ross, P. E. (2017). Watch Yamaha's humanoid robot ride a motorcycle around a racetrack, IEEE Spectrum. Retrieved October 2, 2019, from https://spectrum.ieee.org/cars-that-think/transport ation/self-driving/watch-yamahas-humanoid-robot-ride-a-motorcycle-around-a-racetrack

SailGP. Retrieved October 2, 2019, from https://sailgp.com/

Salerno, M., Zhang, K., Menciassi, A., & Dai, J. S. (2016). A novel 4-DOF origami grasper with an SMA-actuation system for minimally invasive surgery. *IEEE Transactions on Robotics, 32*(6), 484–498.

Samiuddin, O. (2019). ICC to review independent study to see if there is a fine-edge advance to be made in DRS, The National. Retrieved October 2, 2019, from https://www.thenational.ae/ sport/icc-to-review-independent-study-to-see-if-there-is-a-fine-edge-advance-to-be-made-in-drs-1.222557

Siegel, J., Kumar, S., Ehrenberg, I., & Sarma, S. (2016a). Engine misfire detection with pervasive mobile audio. In *Joint European Conference on Machine Learning and Knowledge Discovery in Databases.*

Siegel, J. E., Bhattacharyya, R., Sarma, S., & Deshpande, A. (2016b). Smartphone-based wheel imbalance detection. In *ASME 2015 Dynamic Systems and Control Conference.*

Siegel, J., Bhattacharyya, R.. Sarma, S., & Deshpande, A. (2016c). Smartphone-based vehicular tire pressure and condition monitoring. In *Proceedings of SAI Intelligent Systems Conference.*

Siegel, J. E., Kumar, S., & Sarma, S. E. (2017a). The future internet of things: Secure, efficient, and model-based. *IEEE Internet of Things Journal, 5*(4), 2386–2398.

Siegel, J. E., Bhattacharyya, R., Kumar, S., & Sarma, S. E. (2017b). Air filter particulate loading detection using smartphone audio and optimized ensemble classification. *Engineering Applications of Artificial Intelligence, 66,* 104–112.

Siegel, J. E., Erb, D. C., & Sarma, S. E. (2018a). A survey of the connected vehicle landscape—Architectures, enabling technologies, applications, and development areas. *IEEE Transactions on Intelligent Transportation Systems, 19*(8), 2391–2406.

Siegel, J. E., Sun, Y., & Sarma, S. (2018b). Automotive diagnostics as a service: An artificially intelligent mobile application for tire condition assessment. In *Artificial Intelligence and Mobile Services—AIMS 2018.* Springer.

Siegel, J., Erb, D., & Sarma, S. (2018c). Algorithms and architectures: A case study in when, where and how to connect vehicles. *IEEE Intelligent Transportation Systems Magazine, 10*, 74–87.

Silver, D., Schrittwieser, J., Simonyan, K., Antonoglou, I., Huang, A., Guez, A., et al. (2017). Mastering the game of go without human knowledge. *Nature, 550*, 354.

Standaert, W., & Jarvenpaa, S. (2016). Formula E: Next generation motorsport with next generation fans. In *International Conference on Information Systems.*

Sullivan, L. (2011). The full breakdown on League of Legends' Spectator mode, PC Gamer. Retrieved November 10, 2019, from https://www.pcgamer.com/the-full-breakdown-on-league-of-legends-spectator-mode/

Suzumori, K., & Faudzi, A. A. (2018). Trends in hydraulic actuators and components in legged and tough robots: A review. *Advanced Robotics, 32,* 458–476.

Taborri, J., Agostini, V., Artemiadis, P. K., Ghislieri, M., Jacobs, D. A., Roh, J., & Rossi, S. (2018). Feasibility of muscle synergy outcomes in clinics, robotics, and sports: A systematic review. *Applied Bionics and Biomechanics, 2018*, Article ID 6067807.

Takahashi, D. (2018). Gosu.ai raises $1.9 million to automate game training advice, VentureBeat. Retrieved November 13, 2019, from https://venturebeat.com/2018/03/21/gosu-ai-raises-1-9-million-to-automate-game-training-advice/

Tanaka, K., Matsunaga, K., & Hori, S. (2005). Electroencephalogram-based control of a mobile robot. *Electrical Engineering in Japan, 152,* 39–46.

The Guardian. (2018). Robot skiers tackle Olympic challenge in South Korea, The Guardian. Retrieved October 2, 2019, from https://www.theguardian.com/sport/2018/feb/13/robot-skiers-tackle-olympic-challenge-in-south-korea

Thiel, A., & John, J. M. (2018). Is eSport a 'real' sport? Reflections on the spread of virtual competitions. *European Journal for Sport and Society, 15*(4), 311–315.

The Star Online. Running with an exosuit. Retrieved October 2, 2019, from https://www.thestar.com.my/tech/tech-news/2016/12/12/running-with-an-exosuit

Thomas, G., Gade, R., Moeslund, T. B., Carr, P., & Hilton, A. (2017). Computer vision for sports: Current applications and research topics. *Computer Vision and Image Understanding, 159,* 3–18.

Thrun, S., Montemerlo, M., Dahlkamp, H., Stavens, D., Aron, A., Diebel, J., et al. (2006). Stanley: The robot that won the DARPA grand challenge. *Journal of field Robotics, 23,* 661–692.

Toyama, S., Ikeda, F., & Yasaka, T. (2016). Sports training support method by self-coaching with humanoid robot. *Journal of Physics: Conference Series, 744*(9), 012033.

Toyoda, K., Kono, M., & Rekimoto, J. (2019). Shooting swimmers using aerial and underwater drone for 3D pose estimation. In *International workshop on Human-Drone Interaction, CHI '19.*

Uhlemann, E. (2016). Connected-vehicles applications are emerging [connected vehicles]. *IEEE Vehicular Technology Magazine, 11,* 25–96.

Ujaldón, M. (2016). CUDA achievements and GPU challenges ahead. In *International Conference on Articulated Motion and Deformable Objects* (pp. 207–217). Springer.

Wall, M. (2015). Wow! SpaceX lands orbital rocket successfully in historic first. *SPACE. com.*

Walsh, C. J., Endo, K., & Herr, H. (2007). A quasi-passive leg exoskeleton for load-carrying augmentation. *International Journal of Humanoid Robotics, 4,* 487–506.

Wang, Z., Boularias, A., Mülling, K., Schölkopf, B., & Peters, J. (2017). Anticipatory action selection for human–robot table tennis. *Artificial Intelligence, 247,* 399–414.

Yasumoto, K. (2015). CuraCopter: Automated player tracking and video curating system by using UAV for sport sessions. *SIG Technical Report*. Information Processing Society.

Josh Siegel Ph.D., is an Assistant Professor of Computer Science and Engineering at Michigan State University and the lead instructor for the Massachusetts Institute of Technology's "Internet of Things" and "DeepTech" Bootcamps. His research is focused on Deep Technologies including secure and efficient network connectivity, pervasive sensing and universal diagnostics, and enhanced automated driving. Prior to joining Michigan State, he was a Research Scientist at the Massachusetts Institute of Technology and the founder of CarKnow and DataDriven, two automotive technology companies. Josh is an avid fan of motorsport and he restores and "hacks" cars as well as participates in simulated racing events in his spare time. His section, focused on the role of robotics in sports of the past, present, and future, was inspired by observing how traditional sports enterprises—including some forms of organized motorsport—have begun to adopt bleeding-edge and Deep Technology to maintain or enhance competition, excitement and engagement, and scientific progress.

Daniel Morris Ph.D., is an Associate Professor of Electrical and Computer Engineering at Michigan State University. His research is in machine learning for sensing, sensor fusion, and object tracking with applications in automated driving, patient tremor analysis, and plant phenomics. Prior to joining Michigan State, he developed obstacle detection and classification systems to enable vehicles to drive along dirt roads and through dust and foliage. Daniel is an enthusiastic competitor in Taekwondo, with a second-degree black belt, and has sparred at the USA-Taekwondo National Tournament. He is particularly excited by the long-term challenge of robots outwitting humans and believes it is in sports where we will see this human-machine competition flourish.

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 (Fin Ray Effect, 2013; Kim et al., 2017; Nag, 2017; Nielsen, 2017). 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 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

F. Kirchner (✉)

Robotics Innovation Center, DFKI Bremen, University of Bremen, Bremen, Germany
e-mail: frank.kirchner@dfki.de

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.

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

Not unlike robotics, AI has also seen tremendous development; techniques like Deep Neural Networks (Fukushima, 1980; Nag, 2017; Nielsen, 2017) 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 (Nguyen-Tuong & Peters, 2011; Widhiada et al., 2015), 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] 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

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.).

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 & 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 & 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 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

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

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 (Barry Cooper, 2004; Rolf 1995). 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, 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 & 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 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 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 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
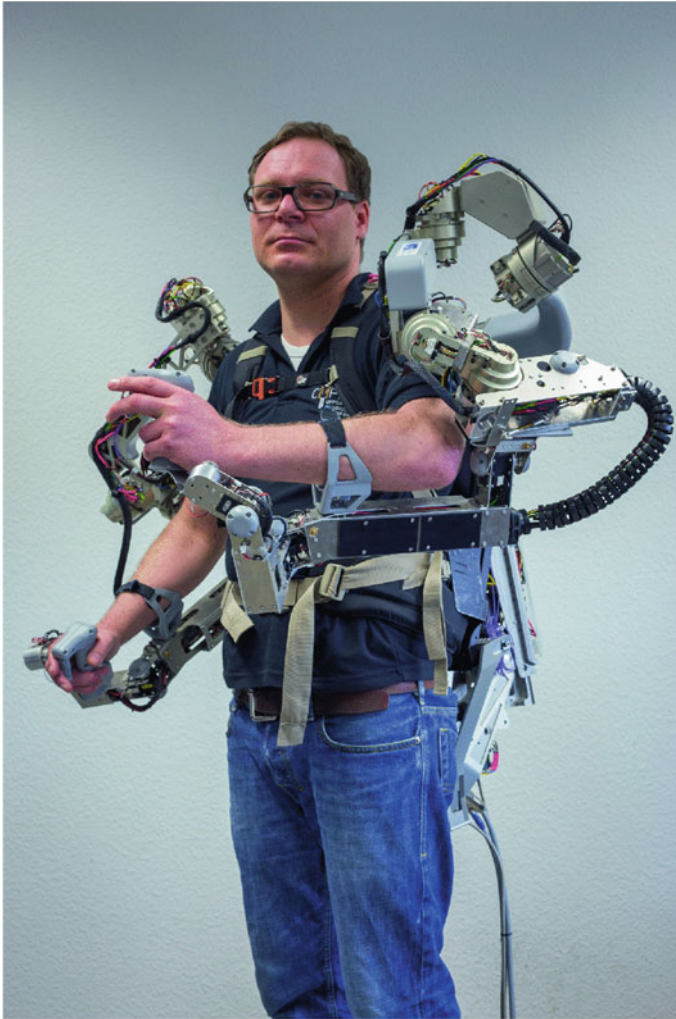
Fig. 5 The upper body exoskeleton. *Photo* DFKI GmbH

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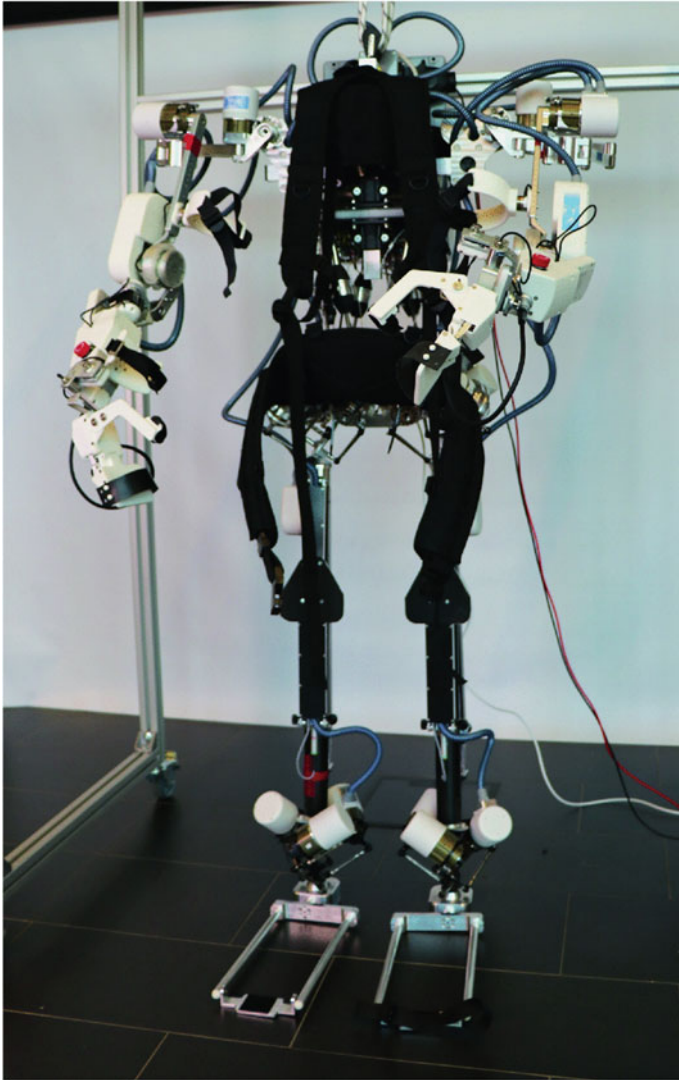
Fig. 6 The full-body exoskeleton for walking support. *Photo* DFKI GmbH

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
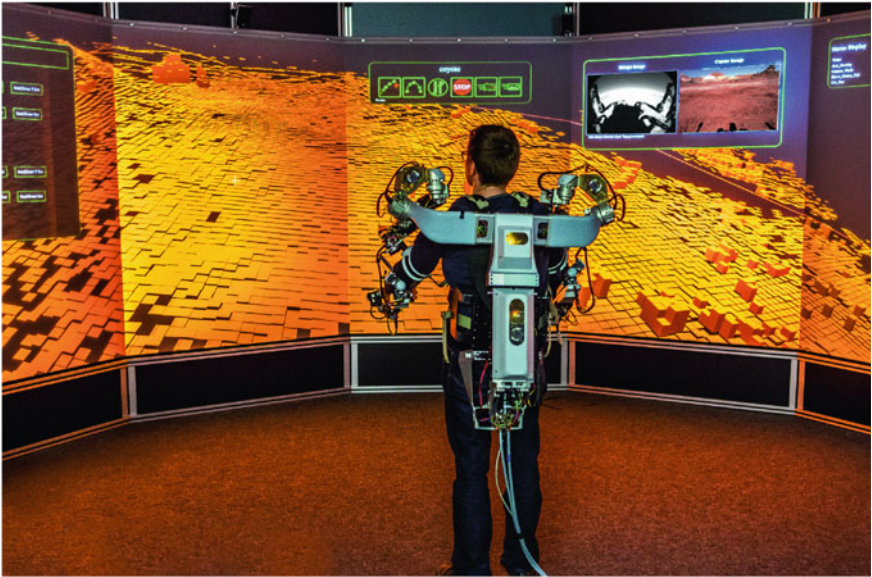
Fig. 7 The upper body skeleton in the cave. *Photo* DFKI GmbH
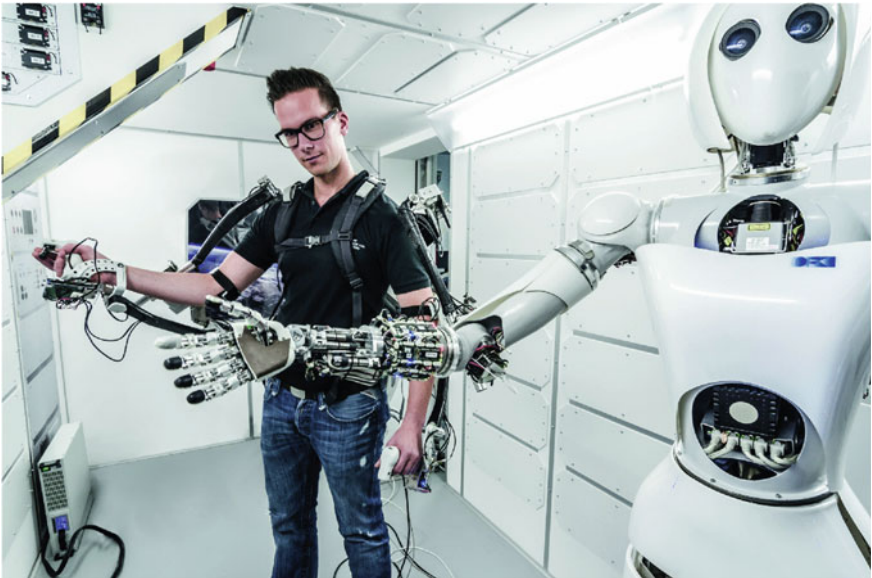
Fig. 8 The passive upper body exoskeleton and the humanoid robot, AILA. *Photo* DFKI GmbH
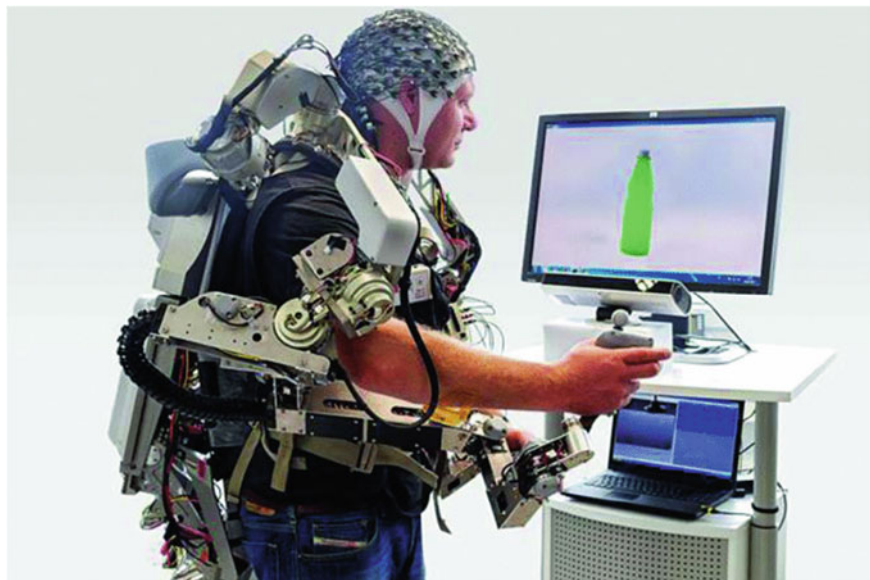
Fig. 9 The upper body exoskeleton and online EEG analysis for intention recognition. *Photo DFKI GmbH*

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 & 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 & 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 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.

References

Barry Cooper, S. (2004). *Computability theory*. Chapman & Hall.

Borecki, L., Tolstych, K., & Pokorski, M. (2013). Computer games and fine motor skills. *Advances in Experimental Medicine and Biology, 755,* 343–348. https://doi.org/10.1007/978-94-007-4546-9_43

Fin Ray Effect. (2013). Retrieved from http://www.bionikvitrine.de/fin-ray-effect.html

Fisher, I. E., Garnsey, M., & Hughes, M. E. (2016). Natural language processing in accounting, auditing and finance: A synthesis of the literature with a roadmap for future research. *Intelligent Systems in Accounting Finance & Management, 23* (3), 157–214. https://doi.org/10.1002/isaf.1386

Fukushima, K. (1980). Neocognitron: A self-organizing neural network model for a mechanism of pattern recognition unaffected by shift in position. *Biological Cybernetics, 36*(4), 93–202. https://doi.org/10.1007/bf00344251

Gallagher, S. (2005). *How the body shapes the mind*. Clarendon Press. https://doi.org/10.1093/0199271941.001.0001

Kim, S.-K., Kirchner, E. A., Stefes, A., & Kirchner, F. (2017). Intrinsic interactive reinforcement learning: Using error-related potentials for real world human-robot interaction. *Nature, 7,* 1–16.

Kirchner F. (2020). AI-perspectives: The turing option. *AI Perspectives, 2*(2), 1–12.

Kitano, H., Asada, M., Kuniyoshi, Y., Noda, I., & Osawa, E. (1995). CiteSeerX—RoboCup: The robot world cup initiative. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.47.9163

Kumar, S., Szadkowski, K. A. V., Mueller, A., & Kirchner, F. (2020). An analytical and modular software workbench for solving kinematics and dynamics of series-parallel hybrid robots. *ASME Journal of Mechanisms Robotics, 12*(2), 1–12. https://doi.org/10.1115/1.4045941

Mohammad, M., & Mattila, J. (2018). Deep learning of robotic manipulator structures by convolutional neural network. In *2018 ninth international conference on intelligent control and information processing (ICICIP).* https://doi.org/10.1109/icicip.2018.8606719

Nag, P. (2017). Google's deep learning AI project diagnoses cancer faster than pathologists. Retrieved from https://www.ibtimes.sg/googles-deep-learning-ai-project-diagnoses-cancer-faster-pathologists-8092

Nguyen-Tuong, D., & Peters, J. (2011). Model learning for robot control: A survey. *Cognitive Processing, 12,* 319–340. https://doi.org/10.1007/s10339-011-0404-1

Nielsen, M. A. (2017). *Neural networks and deep learning*. Determination Press.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27*(1), 169–192.

Rolf, H. (1995). *The universal Turing machine. A half-century*. Springer.

Stoeffler, C., Kumar, S., Peters, H., Brüls, O., Müller, A., & Kirchner, F. (2018). Conceptual design of a variable stiffness mechanism in a humanoid ankle using parallel redundant actuation. In *2018 IEEE-RAS 18th International Conference on Humanoid Robots (Humanoids)*, Beijing, China, pp. 462–468. https://ieeexplore.ieee.org/document/8625046

Thrun, S., Fox, D., & Burgard, W. (2005). *Probabilistic robotics*. The MIT Press.

Trivedi, D., Rahn, C. D., Kier, W. M., & Walker, I. D. (2008). Soft robotics: Biological inspiration, state of the art, and future research. *Applied Bionics and Biomechanics, 5*(3), 99–117.

von Oehsen, T., Fabisch, A., Kumar, S., & Kirchner, F. (2020). *Comparison of distal teacher learning with numerical and analytical methods to solve inverse kinematics for rigid-body mechanisms*. Retrieved from https://arxiv.org/abs/2003.00225

Widhiada, W., Nindhia, T., & Budiarsa, N. (2015). Robust control for the motion five fingered robot gripper. *International Journal of Mechanical Engineering and Robotics Research, 4*, 226–232. https://doi.org/10.18178/ijmerr

Yu, B., de Gea Fernández, J., & Tan, T. (2019). Probabilistic kinematic model of a robotic catheter for 3D position control. *Soft Robotics* 184–194. http://doi.org/10.1089/soro.2018.0074

Frank Kirchner Ph.D., is the Director of the Robotics Innovation Center, Executive Manager of the *German Research Center for Artificial Intelligence* (DFKI) Bremen and the Chair of Robotics at the University of Bremen. He is one of the leading experts in the field of biologically inspired behavior and motion sequences of highly redundant, multifunctional robot systems. In 2013, under Kirchner's leadership and following the model of the DFKI, the Brazilian government founded the *Brazilian Institute of Robotics.* His section, focused on complex robots and AI, was inspired by testing his own control systems in difficult mountain terrain.

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

M. U. Schlegel (✉) · C. Hill
Australian Sports Technologies Network, Melbourne, Australia
e-mail: martin.schlegel@astn.com.au

C. Hill
e-mail: craig.hill@astn.com.au

time, Australian statistics (Commonwealth of Australia, Australian Government—Productivity 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 & 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).

The global COVID-19 pandemic saw remote and connected in-home fitness equipment and service offerings increase rapidly as people were confined to their homes. For example, the interactive fitness equipment platform Peloton reported total revenues growing from $915.0 million in 2019 to $1,825.9 million in 2020 and, again, more than doubling in 2021 to $4,021.8 million (Peloton, 2022). This trend somewhat reversed as people were again able to visit gyms and fitness centers in-person. Furthermore, in December 2020, big tech company Apple launched its Fitness+ subscription service built around the Apple Watch hardware and integrated with Apple phone or tablet devices (Apple, 2020). As such, the pandemic has been identified as a significant factor in the adoption of wearable devices (Osborne, 2021). Overall, the market is expected to continue to grow from about $115 billion in 2021 to $380 billion by 2028 (FnFResearch, 2022).
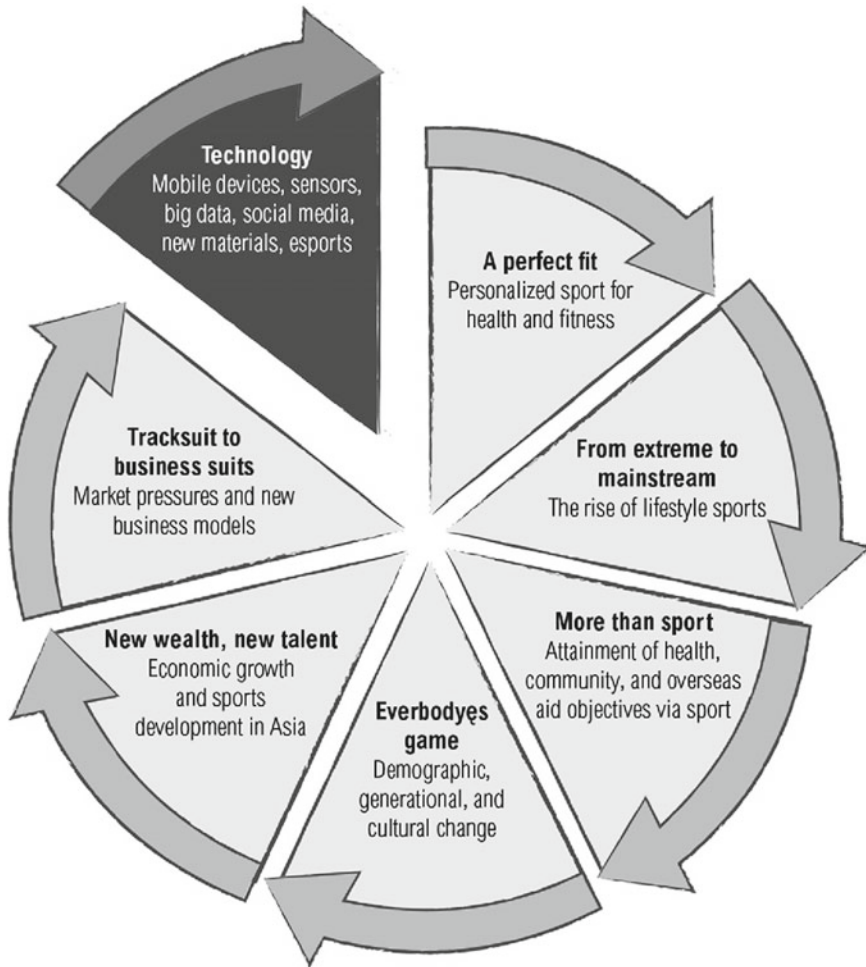
Fig. 1 Megatrends and key drivers in the future of sport. Adopted and amended from Hajkowicz et al. (2013)

More and more, people use the information generated by devices and apps 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
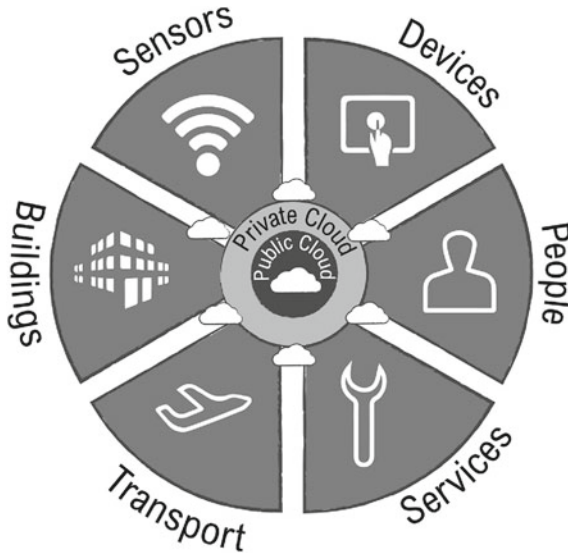
Fig. 2 The internet of things: Networking people, objects and services

consumers who subscribe to their services. Combined with automated synthetic media technologies, for example, personalized instructional videos that are created using 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).

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
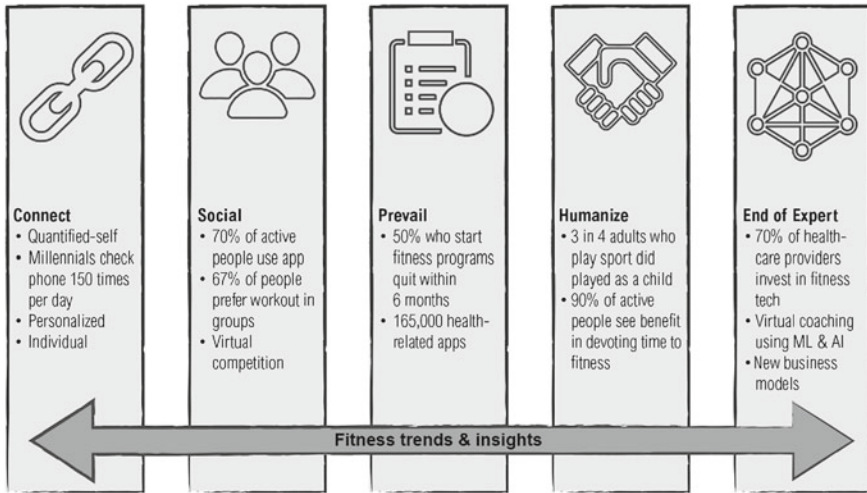
Fig. 3 Insights from fitness survey and resulting trends

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 (Mitchell, 2018; Posner, 2018). One example of a government-led initiative is the 'National Steps Challenge'[TM] launched by the Singapore Health Promotion Board. The initiative rewards Singaporeans seventeen-years of age and older with electronic rewards vouchers when they reach 10,000 steps or more (Ministry of Health Singapore, 2020).

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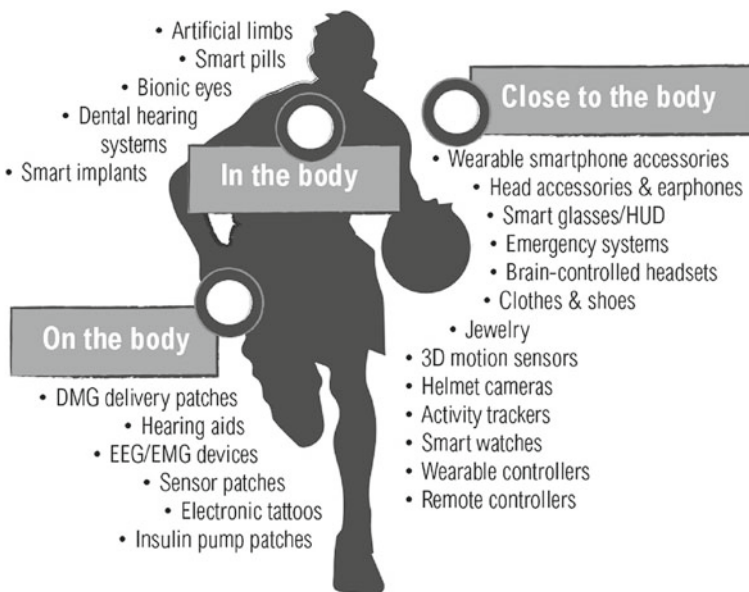
Fig. 4 Location of athlete sensors and devices. Adopted from Stammel (2015)

("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.

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). Startups like Australian VueMotion are deploying advanced image and pose recognition algorithms to analyze an athlete's running movements (www.vuemotion.ai). 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 & 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 & 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 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

---

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

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 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 opportu-
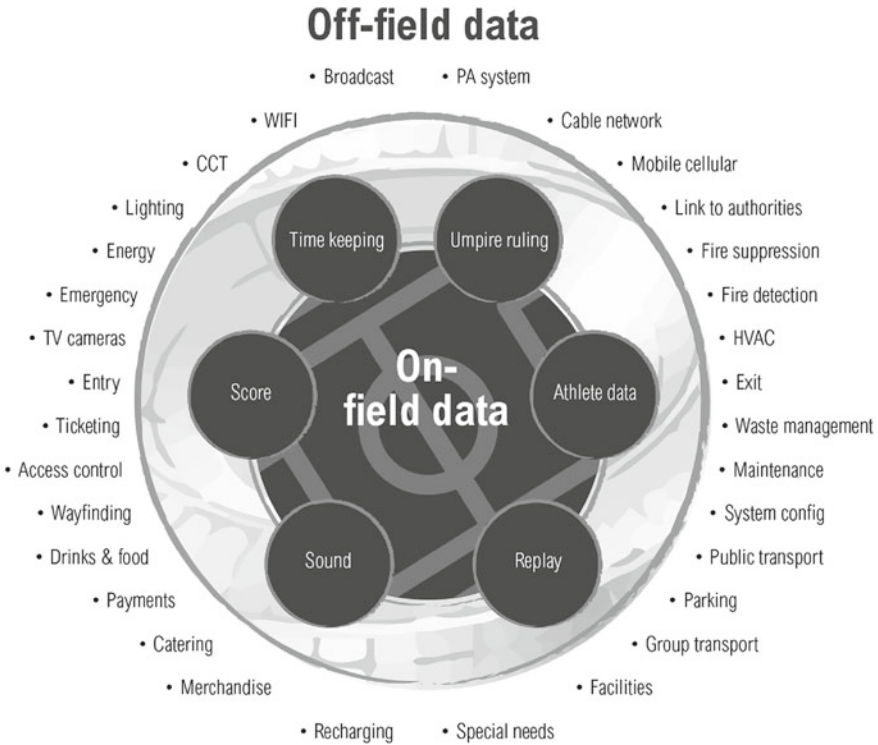
Fig. 5 Digital stadium platform

nity 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-bro adcasting-spalk/). Amateur and grassroots sporting events will also benefit from automated video production systems (Pixellot, 2022; Sport4, 2022).

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 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. It appears as though that streaming of major sports leagues across a multiplicity of different OTT platforms is increasing the risk of a fragmented future in broadcasting (Schlegel, 2022).
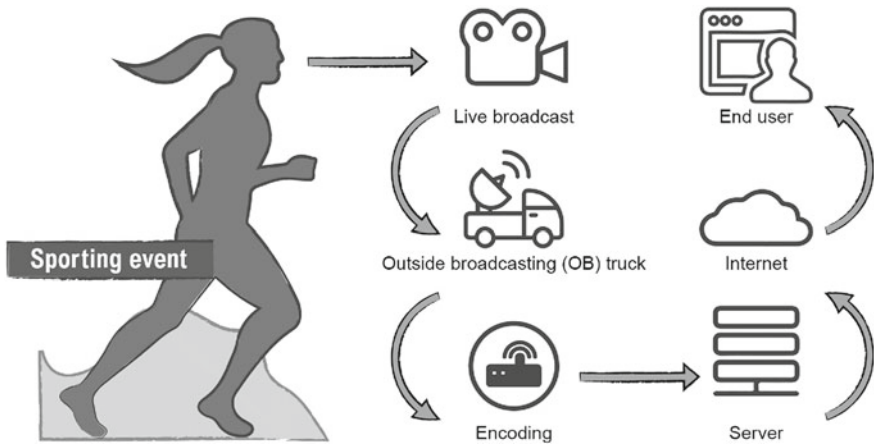
Fig. 6 Over-the-top (OTT) carrier streaming setup resulting in high latency

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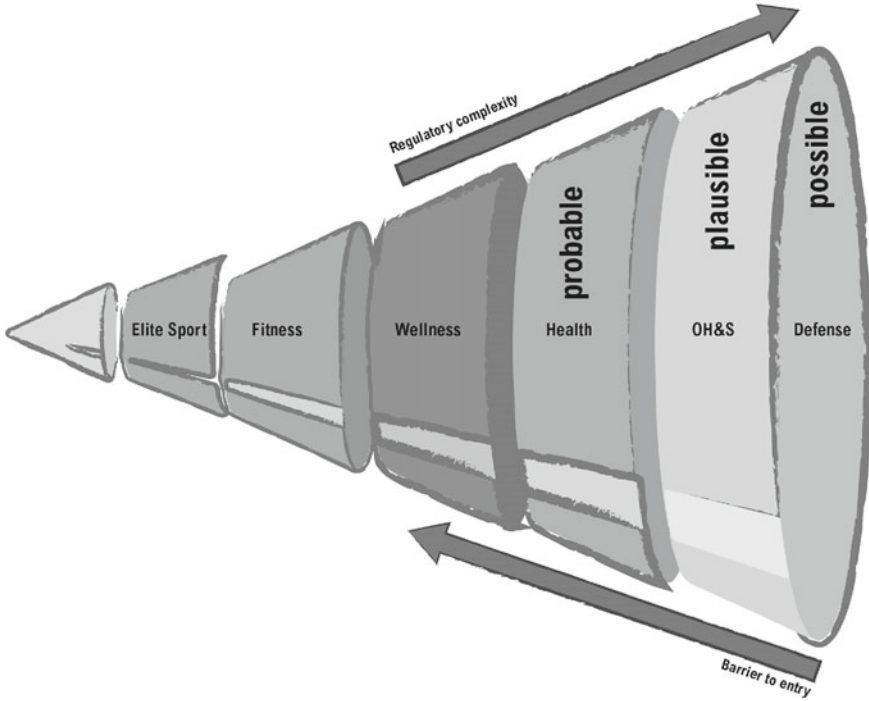
Fig. 7 Technology translation from sport to health, OH&S, and defense

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 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.

6   Conclusion

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 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.
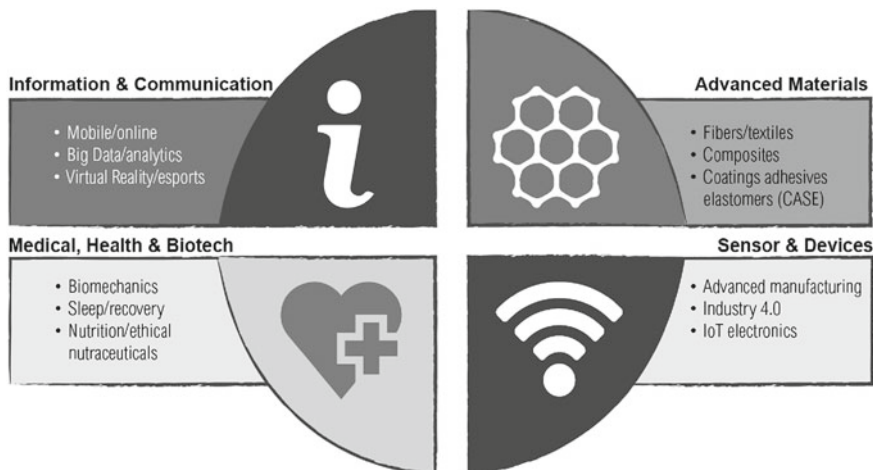
Fig. 8 Areas and aspects of sports technology

References

Advanced Television Ltd. (2020). Survey: 96% of football fans want personalised TV channels. Retrieved February 2020, from https://advanced-television.com/2020/01/16/survey-96-of-football-fans-want-personalised-tv-channels/

Albrecht, U. V., (Ed.). Chances and risks of mobile health apps. Hannover Medical School (2016). Retrieved October 2019, from https://www.bundesgesundheitsministerium.de/fileadmin/Dateien/3_Downloads/A/App-Studie/charismha_abr_v.01.1e-20160606.pdf

Alclear LLC. Retrieved October 2019, from https://www.clearme.com/sports/seahawks

Australian Law Reform Commission. (2012). Insurance in Australia. Retrieved October 2019, from https://www.alrc.gov.au/publication/grey-areas-age-barriers-to-work-in-commonwealth-laws-dp-78/4-insurance/insurance-in-australia/

Apple Inc. (2020). Apple launches Fitness+. Retrieved November 2022, from https://www.apple.com/newsroom/2020/12/apple-fitness-plus-the-future-of-fitness-launches-december-14/.

Belbasis, A., & Fuss, F. K. (2018). Muscle performance investigated with a novel smart compression garment based on pressure sensor force myography and its validation against EMG. *Frontiers in Physiology, 9*, 408. https://doi.org/10.3389/fphys.2018.00408

Burr, S. (2017). Adidas future/fit forecast. Retrieved October 2019, from https://www.gameplan-a.com/wp-content/uploads/2017/03/adidas-Future-Fit-Forecast-2017.pdf

Catapult Sports. Retrieved October 2019, from https://www.catapultsports.com

Commonwealth of Australia. Age discrimination act (2004). Retrieved October 2019, from https://www.legislation.gov.au/Details/C2017C00341

Commonwealth of Australia, Australian Government—Department of Foreign Affairs and Trade (2019). Sports diplomacy 2030. Retrieved Ocotber, 2019, from https://www.dfat.gov.au/sites/default/files/sports-diplomacy-2030.pdf

Commonwealth of Australia, Australian Government—Productivity Commission. Shifting the dial: Why good health matters in Australia, Supporting Paper No. 4 (2017). Retrieved October 2019, from https://www.pc.gov.au/inquiries/completed/productivity-review/report/productivity-review-supporting4.pdf

Commonwealth of Australia. Australian Prudential Regulation Authority Act (1998). Retrieved October 2019, from https://www.legislation.gov.au/Details/C2017C00203

Commonwealth of Australia. Australian Securities and Investments Commission Act (2001). Retrieved October 2019, from https://www.legislation.gov.au/Details/C2018C00438

Convergence Technology Group. Retrieved February 2020, from https://convergencetechnology.com.au

dorsaVi Ltd. Retrieved February 2020, from https://www.dorsavi.com/us/en/visafe/

Düking, P., Fuss, F. K., Holmberg, H.-C., & Sperlich, B. (2018). Recommendations for assessment of the reliability, sensitivity, and validity of data provided by wearable sensors designed for monitoring physical activity. *JMIR Mhealth Uhealth, 6*(4), e102.

Düking, P., Hotho, A., Holmberg, H.-C., Fuss, F. K., & Sperlich, B. (2016). Comparison of non-invasive individual monitoring of the training and health of athletes with commercially available wearable technologies. *Frontiers in Physiology, 7*, 71. https://doi.org/10.3389/fphys.2016.00071

FIFA Football Technology. Retrieved October 2019, from https://football-technology.fifa.com/en/media-tiles/fifa-quality-programme-for-epts/

FIFA Football Technology. Retrieved October 2019, from https://football-technology.fifa.com/en/media-tiles/test-method-for-epts-performance-standard/

FIFA. Retrieved October 2019, from https://football-technology.fifa.com/en/media-tiles/about-goal-line-technology/

FIFA. Retrieved October 2019, from https://football-technology.fifa.com/en/media-tiles/fifa-quality-programme-for-virtual-offside-lines/

FIFA. Retrieved October 2019, from https://football-technology.fifa.com/en/media-tiles/video-assistant-referee-var/

Front Office Sports. Retrieved February 2020, from https://frntofficesport.com/live-sports-broadcasting-spalk/

FnFResearch. (2022). Global Wearable Technology Market. Retrieved November 2022, from https://www.globenewswire.com/news-release/2022/04/13/2421597/0/en/Insights-on-Global-Wearable-Technology-Market-Size-Share-to-Surpass-USD-380-5-Billion-by-2028-Exhibit-a-CAGR-of-18-5-Industry-Analysis-Trends-Value-Growth-Opportunities-Segmentatio.html

Gartner. (2018). *Hype cycle of emerging technologies*. Gartner Inc.

Hajkowicz, S. A., Cook, H., Wilhelmseder, L., & Boughen, N. (2013). *The future of Australian sport: Megatrends shaping the sports sector over coming decades. A consultancy report for the Australian Sports Commission.* CSIRO.

Intel Corporation. Retrieved October 2019, from https://www.intel.com/content/www/us/en/sports/technology/true-view.html

Johan Cruijff Arena. Retrieved October 2019, from https://www.johancruijffarena.nl/default-showon-page/amsterdam-arena-more-energy-efficient-with-battery-storage-.htm

Kagermann, H., Wahlster, W., & Helbig, J. (2013). Recommendations for implementing the strategic initiative Industry 4.0. Retrieved October, 2019 from https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-for-implementing-industry-4-0-data.pdf

Lakhani, K., Fergusson, P., Fleischer, S., Paik, J. H., & Randazzo, S. (2019). *KangaTech*. Harvard Business School Case Collection 619–049

Mitchell, V. (2018). What if the companies that profit from your data had to pay you. Retrieved October 2019, from https://theconversation.com/what-if-the-companies-that-profit-from-your-data-had-to-pay-you-100380

Ministry of Health Singapore. (2020). Singapore Health Promotion Board. National Steps Challenge (TM). Retrieved November 2022, from https://www.healthhub.sg/programmes/37/nsc

Osborne, C. (2021). COVID a factor in wearable device adoption. Retrieved November 2022, from https://www.zdnet.com/article/covid-19-a-significant-factor-in-wearable-device-adoption-market-surge/

Peloton (2022). Annual Reports. Retrieved January 2022, from https://investor.onepeloton.com/financial-information/annual-reports

Pixellot. (2022). Automated Sports Camera. https://www.pixellot.tv

Posner, E. (2018). On cultural monopsonies and data as labor. Retrieved October 2019, from http://ericposner.com/on-cultural-monopsonies-and-data-as-labor/

Quantified Self. Retrieved October, 2019, from https://quantifiedself.com

Saylor, K., & Nicolella, D. (2019). Markerless biomechanics for cycling. Southwest Research Institute. Retrieved October 2019, from https://www.swri.org/sites/default/files/brochures/markerless-biomechanics-cycling.pdf

Schlegel, M. (2022). Risk of a fragmented future in sports broadcasting. https://www.chemneera.com/news-and-resources/risk-of-fragmented-future-in-sports-broadcasting

Solmaz-Kaiser, A. (2017). Wearable device: Safety beyond compliance. TUV Sud Whitepaper. Retrieved October 2019, from https://www.tuvsud.com/en/resource-centre/white-papers/wearable-devices-safety-beyond-compliance

Sports Business Consulting. (2018). Global Media Report 2018. Retrieved October, 2019, from https://www.sportbusiness.com/2018/11/sportbusiness-consulting-global-media-report/

Sport4. (2022). Sports Streaming and Automation. https://www.sport4.com.au

Stammel, C. (2015). Wearable technologies. Retrieved October 2019, from https://www.wearable-technologies.com/

Takahashi, D. (2017). Retrieved October 2019, from https://venturebeat.com/2017/05/22/study-shows-live-mobile-sports-apps-are-lagging-behind-real-time-sports-tv-broadcasts/

The Arsenal Football Club plc. Retrieved October 2019, from https://www.arsenal.com/news/3mw-battery-power-emirates-stadium

TRACK Landscape Architecture. Retrieved October 2019, from https://www.track-landscapes.com/track

United States Food and Drug Administration (FDA). Retrieved October 2019, from https://www.fda.gov/medical-devices/digital-health

VALD Performance. Retrieved October 2019, from https://www.valdperformance.com/humantrak-movement-analysis-system/

VICON Motion Capture Systems. Retrieved October 2019, from https://www.vicon.com

Voros, J. (2003). A generic foresight process framework. *Foresight, 5*(3), 10–21.

VueMotion human movement analysis. Retrieved August 2023, from https://www.vuemotion.ai/home

Wheeler, T. (2017). Retrieved October 2019, from https://www.sporttechie.com/judge-rules-for-golden-state-dismisses-august-eavesdropping-suit/

Martin Schlegel is Executive Chair of the Australian Sports Technologies Network (ASTN) focusing on start-up programs, global partnerships with other clusters of innovation and facilitating export growth of sports technology companies. With a background in advanced materials, technology and business, Martin engages globally with various stakeholders across the sports technology and sport business industry. He previously worked on major sports infrastructure projects across Australia, Asia, Europe, and the USA, including sports surfacing projects for the 2008 and 2012 Olympic Games. In his leisure time, he and his wife actively track their sporting activities and test various wearables; he also enjoys various codes of football with his son and daughter, whom he actively coached during their time in junior sport.

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.

D. Beiderbeck (✉)
Center for Sports and Management, WHU - Otto Beisheim School of Management, Dusseldorf, Germany
e-mail: daniel.beiderbeck@whu.edu

H. Krüger
Center for Sports and Management, WHU-Otto Beisheim School of Management, Dusseldorf, Germany
e-mail: harry.krueger@whu.edu

T. Minshall
Institute for Manufacturing, IfM's Centre for Technology Management, University of Cambridge, Cambridge, UK
e-mail: thwm100@cam.ac.uk

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 & 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
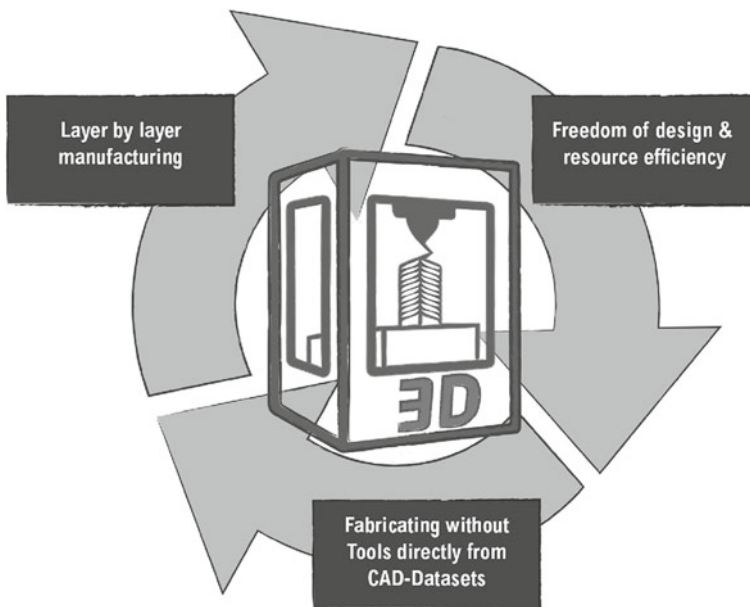
Fig. 1   AM process advantages

along the value chain compared to traditional manufacturing methods (see Figs. 2 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 & Idacavage, 2016) to metals, ceramics (Owen et al., 2018; Todd, 2017) and nontraditional materials, including organic cells or tissues (Murphy & 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 & 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).
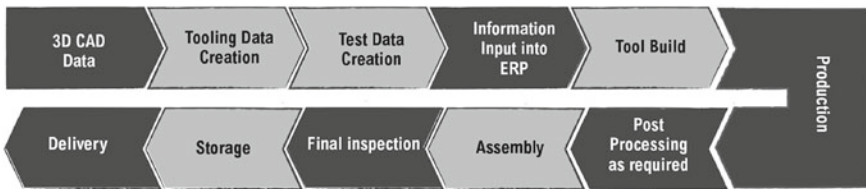
Fig. 2 Traditional manufacturing value chain
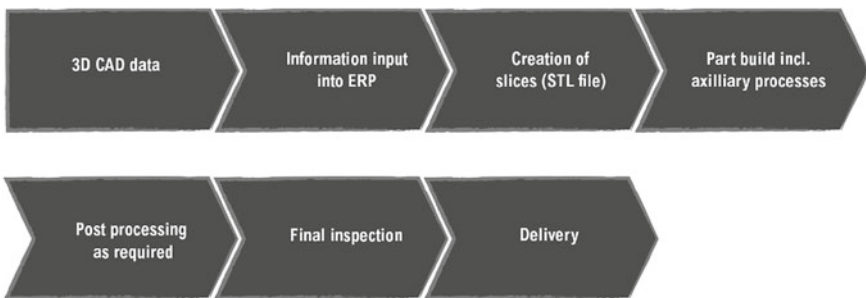
Fig. 3 AM value chain

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.

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 &
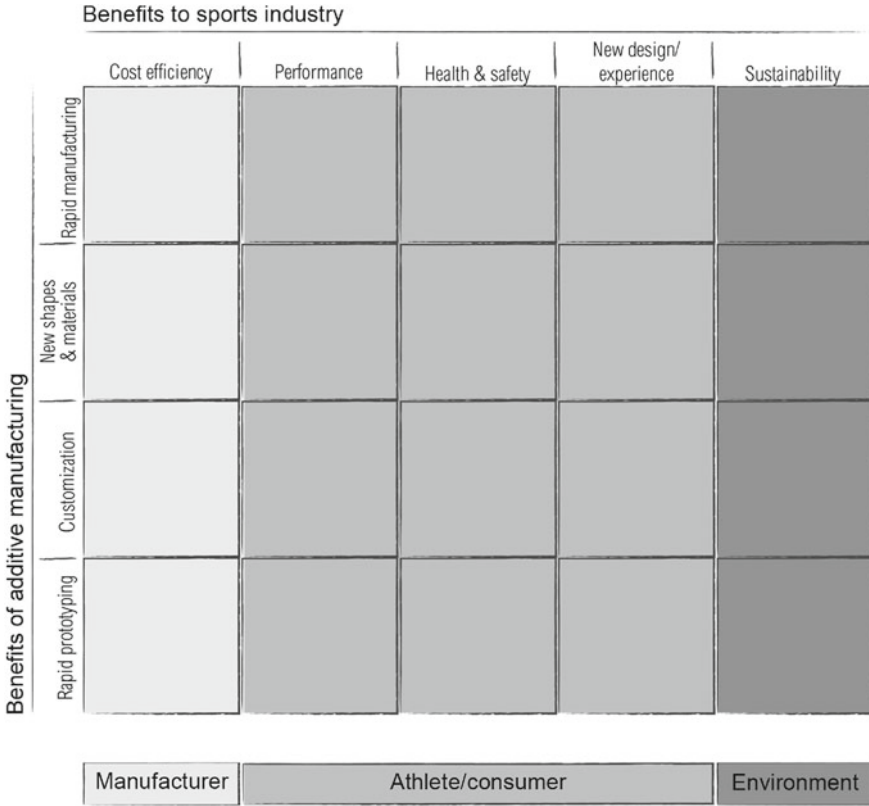
Fig. 4 AM sports application matrix

Ford, 2015). On the one hand, if a product is fabricated in a sustainable way, it might increase 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

[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/.

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). 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 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.

---

[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-par ley-oceans-setzen-paris-ein-zeichen/.
[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/wor ldwide.

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

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

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, Oliver 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 transmission 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 components**	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 Paralympics. 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

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

Benefits to sports industry

Cost efficiency | Performance | Health & safety | New design/experience | Sustainability

Rapid manufacturing
- Performance: 11
- New design/experience: 3
- Sustainability: 3

New shapes & materials
- Cost efficiency: 16 28 30
- Performance: 6 7 4 18 24 26 28 30
- Health & safety: 1 9 26
- New design/experience: 1 6 14 15 18 21 28 30
- Sustainability: 3 14 15 28

Customization
- Cost efficiency: 16 19 21 22 23 24 25 27 29
- Performance: 1 2 4 6 9 10 11 12 13 14 15 17 18 22 23 24 25 26 29
- Health & safety: 1 2 4 5 8 9 19 20 21 22 23 24
- New design/experience: 1 2 4 10 11 19 20 21 22 23 24 25 27

Rapid prototyping
- Cost efficiency: 1 4 5 7 9 13 16 17 29
- Performance: 7
- Sustainability: 1

Benefits of additive manufacturing

Manufacturer | Athlete/consumer | Environment

Fig. 6 Current AM use cases in the AM sports application matrix

putting trainers, training masks that simulate high altitude breathing, exact copies of 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.

---

[14] https://www.3dnatives.com/en/4d-printing-disrupting-current-manufacturing-techniques-230920194/.

- **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.
- **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 Grab-CAD 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

---

[15] https://nanoss.de/de/nano3dsense-der-erste-3d-drucker-in-konkurrenzloser-nanometer-praezision/.

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

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 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 Vapor-fly 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

---

[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.

allow athletes to use nanobots to drive performance to the limits. We may or may not like this vision, but technology–including AM—will 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.

References

3D printed ballet shoe 'P-rouette' reduces pain and injuries for dancers | All3DP. Retrieved December 20, 2019, from. https://all3dp.com/4/3d-printed-ballet-shoe-p-rouette-reduces-pain-injuries-dancers/

3D printing golf clubs and equipment. February 07, 2020, from. https://3dprint.com/219546/3d-print-golf-clubs-and-equipment/

3D printed handlebars help set world record. Retrieved February 07, 2020, from. https://all3dp.com/3d-printed-handlebars-world-record/

3D printed protective face masks for football players. Retrieved February 07, 2020, from. https://3dprinting.com/news/new-3d-printed-protective-face-masks-football-players/

3D printed putting trainer helps golfers observe new USGA rule. Retrieved February 07, 2020, from. https://3dprint.com/43532/in-sync-3d-putting-trainer/

3D printed Shin Guards review (Zweikampf). Retrieved February 07, 2020, from. https://thesoccerreviews.com/2018/03/16/3d-printed-shin-guards-review-zweikampf/

3D printing in sport: Feature story. Retrieved February 07, 2020, from. https://www.3dnatives.com/en/3d-printing-sport-201220174/

3-D printing: the future of climbing holds? Retrieved February 07, 2020, from. https://www.climbing.com/gear/3-d-printing-the-future-of-climbing-holds/

3D printed shoes. Retrieved October 12, 2019, from. https://all3dp.com/topic/3d-printed-shoes/

A 3D printed mannequin of Tom Dumoulin in the TU Delft wind tunnel helps gain a competitive advantage. February 07, 2020, from. https://www.tudelft.nl/en/2016/tu-delft/a-3d-printed-mannequin-of-tom-dumoulin-in-the-tu-delft-wind-tunnel-helps-gain-a-competitive-advantage/

Adidas and Parley for the oceans setzen in Paris ein Zeichen. Retrieved January 22, 2020, from. https://www.adidas-group.com/de/medien/newsarchiv/pressemitteilungen/2015/adidas-und-parley-oceans-setzen-paris-ein-zeichen/

Adidas to double production of ocean plastic trainers in 2019. Retrieved January 22, 2020, from. https://www.edie.net/news/5/Adidas-to-double-production-of-ocean-plastic-trainers-for-2019/

Adidas unveils industry's first application of digital light synthesis with Futurecraft 4D. February 07, 2020, from. https://www.adidas-group.com/en/media/news-archive/press-releases/2017/adidas-unveils-industrys-first-application-digital-light-synthes/

Adidas—Adidas breaks the mould with 3D-printed performance footwear. Retrieved October 07, 2019, from. https://www.adidas-group.com/en/media/news-archive/press-releases/2015/adidas-breaks-mould-3d-printed-performance-footwear/

Ahn, S. H., et al. (2015). Nanoscale 3D printing process using aerodynamically focused nanoparticle (AFN) printing, micro-machining, and focused ion beam (FIB). *CIRP Annals Manufacturing. Technology, 64*(1), 523–526.

Athletic footwear—Worldwide | Statista Market Forecast. February 07, 2020, from. https://www.statista.com.login.bibproxy.whu.edu/outlook/11020000/100/athletic-footwear/worldwide

Atzeni, E., & Salmi, A. (2012). Economics of additive manufacturing for end-usable metal parts. *International Journal of Advanced Manufacturing Technology, 62*(9–12), 1147–1155.

Balmer, N., Pleasence, P., & Nevill, A. (2012). Evolution and revolution: Gauging the impact of technological and technical innovation on olympic performance. *Journal of Sports Sciences, 30*(11), 1075–1083

Beiderbeck, D., Deradjat, D., & Minshall, T (2018). The Impact of Additive Manufacturing Technologies on Industrial Spare Parts Strategies. *Centre for Technology Management Working Paper Series*

Bourell, D. L., Beaman, J. J., Leu, M. C., & Rosen, D. W. (2009). A brief history of additive manufacturing and the 2009 roadmap for additive manufacturing: looking back and looking ahead. In *Proceedings of Rapid Tech*, 2009.

Burton snowboards uses 3d printing to solve longtime snowboarding conundrum. February 07, 2020, from. https://3dprint.com/159425/burton-snowboards-3d-printing/

Carbon is 3D printing custom football helmet liners for Riddell. February 07, 2020, from. https://techcrunch.com/2019/02/01/carbon-is-3d-printing-custom-football-helmet-liners-for-riddell/

Cooper, D. E., Stanford, M., Kibble, K. A., & Gibbons, G. J. (2012). Additive manufacturing for product improvement at Red Bull technology. *Materials and Design, 41,* 226–230.

Deradjat, D., & Minshall, T. (2017). Implementation of rapid manufacturing for mass customisation implementation of rapid manufacturing for mass customisation. *Journal of Manufacturing Technology Management, 28*(21), 95–121.

Despeisse, M., & Ford, S. (2015). The role of additive manufacturing in improving resource efficiency and sustainability. *IFIP Advances in Information and Communication Technology, 460,* 129–136.

Dyer, B. (2015). The progression of male 100 m sprinting with a lower-limb amputation 1976–2012. *Sports, 3*(1), 30–39.

Eliud Kipchoge 1:59 Attempt Kit Nike Next%—Nike News. Retrieved 13 January 2020. https://news.nike.com/news/eliud-kipchoge-1-59-attempt-kit-nike-zoom-marathon-shoe

FINA Approved swimwear. Retrieved January 13, 2020, from. http://www.fina.org/content/fina-approved-swimwear.

First all 3D printed cleats by prevolve. February 07, 2020, from. https://3dshoes.com/blogs/news/first-ever-100-3d-printed-cleats.

French athletes develop customised 3D printed shooting equipment. February 07, 2020, from. https://3dprintingindustry.com/news/french-athletes-develop-customised-3d-printed-shooting-equipment-144931/.

Fully customizable tennis racket handle. February 07, 2020, from. https://3dprinting.com/news/customizable-tennis-racket-handle/.

Gebhardt, A. (2012). Understanding additive manufacturing rapid prototyping—Rapid tooling—Rapid manufacturing. *Carl Hanser, München*, 591.

Gibson, I., Rosen, D. W., & Stucker, B. (2015). *Additive manufacturing technologies: 3D printing, rapid prototyping and direct digital manufacturing*, 2nd Ed. Springer.

Greatest 3D Printed Houses, Buildings and Constructions. Retrieved January 22, 2020, from. https://all3dp.com/1/3d-printed-house-building-construction/

Here's how Nike is innovating to scale up its manufacturing. Retrieved October 07, 2019. https://www.forbes.com/sites/greatspeculations/2016/05/18/heres-how-nike-is-innovating-to-scale-up-its-manufacturing/#335ab3801497

Hopkinson, N., Hague, R., & Dickens, P. (2005). Rapid manufacturing. *An industrial Revolution for the Digital Age.* Neil Hopkinson, Richard Hague, Philip Dickens. Wiley, p. 304.

How 3D printed sports equipment is changing the game. February 07, 2020, from. https://3dprinting.com/3d-printing-use-cases/how-3d-printed-sports-equipment-is-changing-the-game/

How 3D printing impacts PUMA and Reebok. February 07, 2020, from. https://www.3ders.org/articles/20130308-how-3d-printing-impacts-puma-and-reebok-in-designing-and-prototyping.html

How Eliud Kipchoge Helped Perfect Nike's 3D printing process for uppers—Nike news. Retrieved January 13, 2020, from. https://news.nike.com/news/eliud-kipchoge-3d-printed-nike-zoom-vaporfly-elite-flyprint

How team USA used 3D printing to build a better luge. February 07, 2020, from. https://techcr
unch.com/2018/02/14/how-team-usa-used-3d-printing-to-build-a-better-luge/?guccounter=1

How will 4D printing disrupt our current manufacturing techniques? February 07, 2020, from.
https://www.3dnatives.com/en/4d-printing-disrupting-current-manufacturing-techniques-230
920194/

Intel and chromat unveil curie-powered 3d printed responsive sports bra that prevents excessive
sweating. February 07, 2020, from. https://www.3ders.org/articles/20150915-intel-chromat-
unveil-curie-powered-3d-printed-responsive-sports-bra.html

Kajtaz, M., Subic, A., Brandt, M., & Leary, M. (2019). Three-dimensional printing of sports
equipment. In: *Materials in Sports Equipment*. Elsevier, pp. 161–198.

Kaldos, A., Pieper, H. J., Wolf, E., & Krause, M. (2004). Laser machining in die making—A
modern rapid tooling process. *Journal of Materials Processing Technology, 155–156*(1–3),
1815–1820.

Killi, S. W., & Kempton, W. L. (2018). The impact of making: investigating the role of the 3d
printer in design prototyping. In: *Additive Manufacturing*. Pan Stanford, pp. 111–141.

Kyle, S. (2018). 3D printing of bacteria: The next frontier in biofabrication. *Trends in Biotechnol-
ogy*, *36*(4), 340–341 (Elsevier Ltd.)

Liu, R., Wang, Z., Sparks, T., Liou, F., & Newkirk, J. (2017). Aerospace applications of laser addi-
tive manufacturing. In: *Laser Additive Manufacturing: Materials, Design, Technologies, and
Applications* (pp. 351–371). Elsevier Inc.

Modla X reebok 3D printed Athlete's Mask. February 07, 2020, from. https://3dprintingindustry.
com/news/interview-modla-x-reebok-3d-printed-athletes-mask-127245/

Murphy, S. V., & Atala, A. (2014). 3D bioprinting of tissues and organs. *Nature Biotechnology*,
32(8), 773–785 (Nature Publishing Group).

Nano 3D Sense: Der erste 3D-Druck mit echter Nanometer-Präzision. February 07, 2020, from.
https://nanoss.de/de/nano3dsense-der-erste-3d-drucker-in-konkurrenzloser-nanometer-praezi
sion/

New balance working with 3D printing company to develop high performance running shoes.
Retrieved October 07, 2019, from. https://www.sporttechie.com/new-balance-working-3d-pri
nting-company-develop-high-performance-running-shoes/

New stamping ground for Nike and Adidas as 3D shoes kick off. Retrieved October 07, 2019, from.
https://www.ft.com/content/1d09a66e-d097-11e2-a050-00144feab7de

Nike Vaporfly 4%: Innovation… Or Tech Doping? Retrieved 13, January 2020. https://www.
forbes.com/sites/enriquedans/2020/02/06/nike-vaporfly-4-innovation-or-techdoping/#116f0f
665919

Normals are 3D-printed earbuds made just for you. February 07, 2020, from. https://www.theverge.
com/2014/7/8/5878733/normals-3d-printed-earbuds-nikki-kaufman-normal.

Olympic fencers get a grip with Stratasys 3D printers. February 07, 2020, from. http://blog.strata
sys.com/2013/08/28/3d-printed-fencing-hilt-tsukuba-university/.

OS additive manufacturing for bike hub and drive assembly. February 07, 2020, from. https://www.
eos.info/press/customer_case_studies/kappius.

Owen, D., et al. (2018). 3D printing of ceramic components using a customized 3D ceramic printer.
Progress in Additive Manufacturing, 3(1–2), 3–9.

Phoenix | white—Oliver cabell. February 07, 2020, from. https://olivercabell.com/products/pho
enix-white

Reebok releases liquid factory 3D printed floatride run sneakers in the U.S.—3D printing industry.
Retrieved 07 Oct 2019. https://3dprintingindustry.com/news/reebok-releases-liquid-factory-3d-
printed-floatride-run-sneakers-u-s-131033/

Snowboard-Kern aus dem 3D-Drucker: Wie CIME Wintersport verändert. February 07, 2020,
from. https://www.ispo.com/produkte/snowboard-kern-aus-dem-3d-drucker-wie-cime-winter
sport-veraendert

Stamping out chronic foot disease in horses. February 07, 2020, from. https://www.csiro.au/en/Res
earch/MF/Areas/Metals/Lab22/Horseshoe

Stansbury, J. W., & Idacavage, M. J. (2016). 3D printing with polymers: Challenges among expanding options and opportunities. *Dental Materials, 32*(1), 54–64.

Stratasys hits the slopes with 3D printed skis. February 07, 2020, from. http://blog.stratasys.com/2014/02/13/3d-printed-skis/

StringKing calls on lacrosse players to up their game with 3D printed heads. February 07, 2020, from. https://www.3ders.org/articles/20161117-stringking-calls-on-lacrosse-players-to-up-their-game-with-3d-printed-heads.html

Tailored fits AG. Retrieved December 20, 2020 from. https://www.tailored-fits.com/en/

The best 3D printed safety equipment project. February 07, 2020, from. https://www.sculpteo.com/blog/2019/02/20/top-5-3d-printed-sports-safety-equipment-projects-what-is-possible/

The Best Thingiverse Alternatives. Retrieved December 13, 2019, from. https://all3dp.com/2/best-thingiverse-alternatives/

This 3D-printed bicycle is stronger than titanium. February 07, 2020, from. https://mashable.com/2018/05/18/arevo-3d-printer-bicycle/?europe=true

Todd, I. (2017). Printing steels. *Nature Materials, 17*(1), 13–14. Nature Publishing Group.

When a fencing manufacturer goes designer. February 07, 2020, from. https://www.leonpaul.com/blog/when-a-fencing-manufacturer-goes-designer-3-3-3d-printing-a-fencing-mask/

World Athletics denies tipping off Nike over new running-shoe regulations. Retrieved January 13, 2020, from. https://www.theguardian.com/sport/2020/feb/06/world-athletics-foot-down-nike-running-shoe-regulations

World first 3D printed sports wheelchair seat used by Paralympics games. February 07, 2020, from. https://www.3ders.org/articles/20120904-world-first-3d-printed-sports-wheelchair-seat-used-by-paralympics-games.html

Daniel Beiderbeck is Head of Projects and Development Sport at Borussia Dortmund (BVB). He has a Ph.D. from WHU—Otto Beisheim School of Management, Center for Sports and Management, in Germany, and is still affiliated with research topics at the center. His research interests include technology foresight in the context of football and leadership in times of uncertainty. His work has been published in books, the Centre for Technology Management and Working Paper Series at Cambridge University, among others. Before stepping into academia and business, Daniel was an active player at SV Rödinghausen. Despite some talent, he trusted his foresight capabilities in early years and decided to focus more on his career off the pitch than on the pitch—though he's surely never lost his passion for the sport.

Harry Krüger is a research assistant at the Center for Sports and Management (CSM) at WHU—Otto Beisheim School of Management. His research looks at the work of sporting directors of professional football clubs with a focus on value generation from team management. Before joining the CSM, he worked as a consultant for McKinsey & Company, Inc., dealing with semiconductor manufacturing, data analytics, and machine learning. He is particularly interested in ways to unlock the potential of additive manufacturing by using advanced data analysis. In his spare time, Harry enjoys playing and watching soccer and suffering with his favorite team, FC Energie Cottbus.

Tim Minshall, Ph.D., is the inaugural Dr. John C. Taylor Professor of Innovation at the University of Cambridge, Head of the Institute for Manufacturing (IfM), and Head of the IfM's Centre for Technology Management. His research, teaching, and engagement activities are focused on the link between manufacturing and innovation. In his early career, he worked as a teacher, consultant, plant engineer, and freelance writer in the UK, Australia, and Japan. Today, he is still actively involved in outreach activities to raise awareness of engineering and manufacturing among primary and secondary school children and their teachers.

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

D. W. Hutmacher (✉)

Centre for Biomedical Technologies, Queensland University of Technology, Brisbane, Australia
e-mail: dietmar.hutmacher@qut.edu.au

Max Planck Queensland Center (MPQC) for the Materials Science of Extracellular Matrices, QUT, Brisbane, Australia

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, 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 & Rodeo, 2019). Regenerative medicine may be defined as the process of replacing or "regenerating" human cells, tissues or organs to restore or establish normal function. https://www.fda.gov/vaccines-blood-biologics/cellular-gene-therapy-products/regenerative-medicine-advanced-therapy-designation.

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 (Stafford 2nd et al., 2020). 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).

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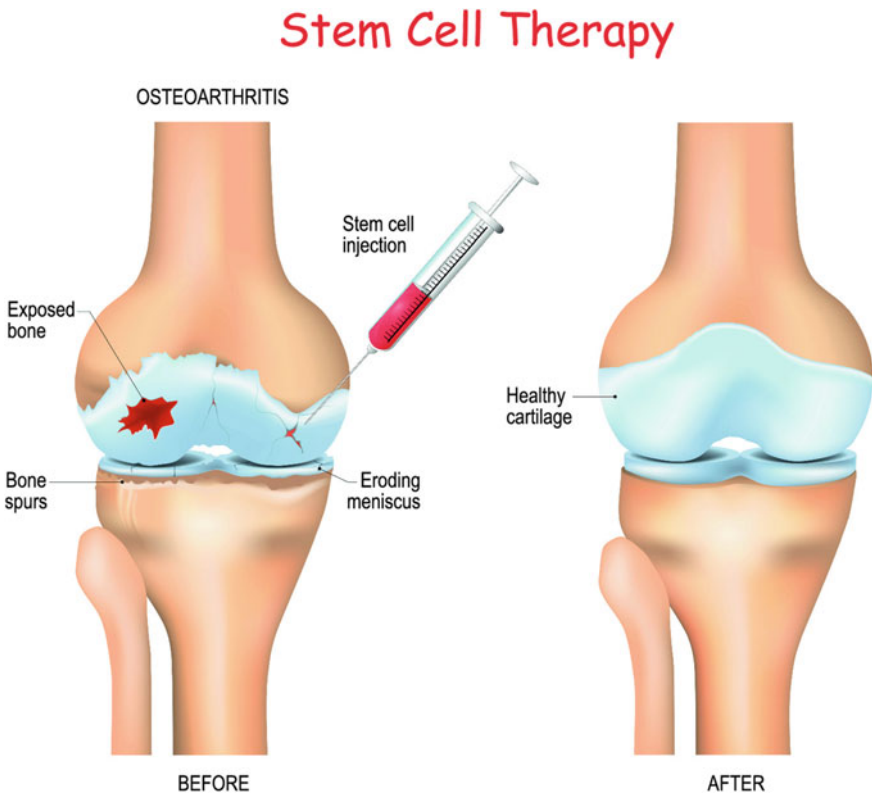
Fig. 1 Cell therapy concept for cartilage repair after trauma sports injury or tissue degeneration from exercise

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 (Kon et al., 2020).

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 & 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 (Liebig et al., 2020).

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 (Chou et al., 2020; Scully & Matsakas, 2019) (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

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

example, two mice were sutured together in such a way that they shared a circulatory blood system. Researchers found that when old mice were 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 16–25. 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 (Zhou et al., 2020a).

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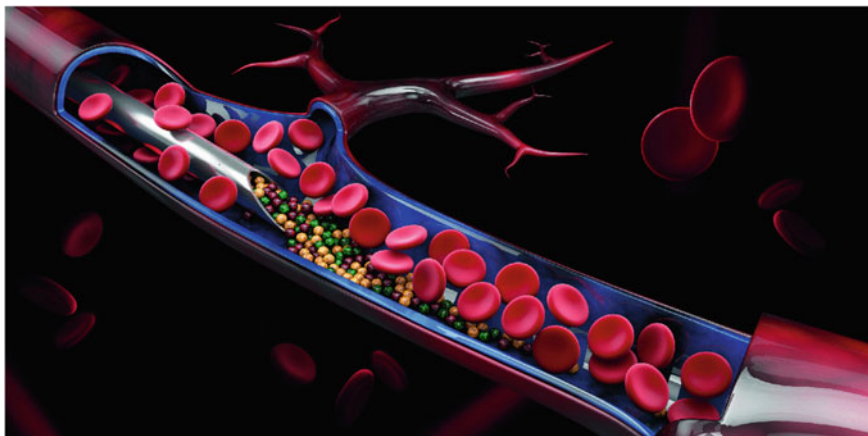
Fig. 3 Regenerative potential of injection of exosomes has been reported in some sports patients with OA. It is reasonable to believe that more regenerative potential of exosomes will be discovered in the future

vesicles (EV) have been most recently applied as biomarkers for disease diagnosis, prognosis, and even injury conditions since their levels or contents might change 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 (Zhou et al., 2020b).

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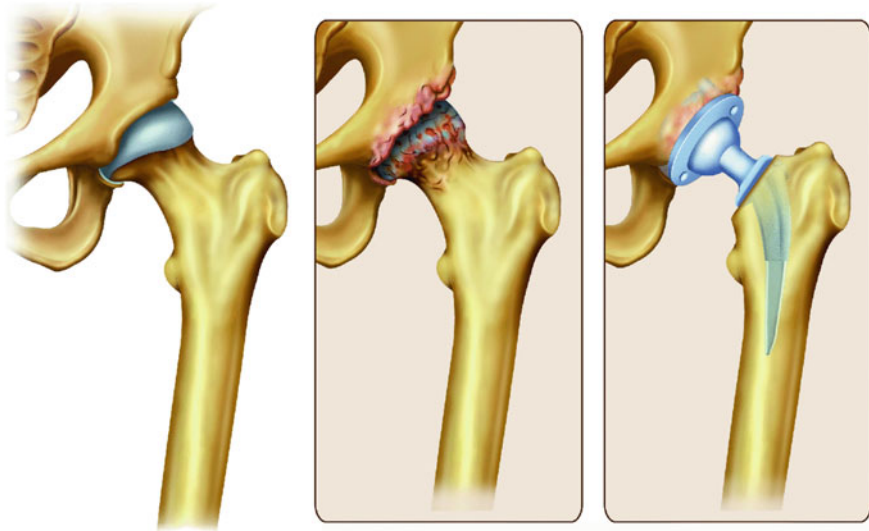
Fig. 4 Hip replacement surgery is commonly performed to treat hip conditions such as severe osteoarthritis. Globally, over two million total hip replacements are performed annually

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.

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.

References

Administrator, E. R. N. A. (2018, June 22). *Exosomes hit the mainstream as elite NFL athlete undergoes stem cell-derived extracellular vesicle therapy*. Retrieved April 1, 2020, from https://www.exosome-rna.com/exosomes-hit-the-mianstream-as-elite-nfl-athlete-undergoes-stem-cell-derived-extracellular-vesicle-therapy/

Borg-Stein, J., Osoria, H. L., & Hayano, T. (2018). Regenerative sports medicine: Past, present, and future (adapted from the PASSOR Legacy Award presentation; AAPMR; October 2016). *PM R, 10*, 1083–1105. https://doi.org/10.1016/j.pmrj.2018.07.003

Chou, T. M., Chang, H. P., & Wang, J. C. (2020). Autologous platelet concentrates in maxillofacial regenerative therapy. *Kaohsiung Journal of Medical Sciences.* https://doi.org/10.1002/kjm2.12192

Dehghani, B., & Rodeo, S. (2019). Cell therapy-a basic science primer for the sports medicine clinician. *Current Reviews in Musculoskeletal Medicine, 12*, 436–445. https://doi.org/10.1007/s12178-019-09578-y

Hutmacher, D. W., et al. (2015). Convergence of regenerative medicine and synthetic biology to develop standardized and validated models of human diseases with clinical relevance. *Current Opinion in Biotechnology, 35*, 127–132. https://doi.org/10.1016/j.copbio.2015.06.001

Johal, H., et al. (2019). Impact of platelet-rich plasma use on pain in orthopaedic surgery: a systematic review and meta-analysis. *Sports Health, 11*, 355–366. https://doi.org/10.1177/1941738119834972

Jones, I. A., Togashi, R. C., & Thomas Vangsness, C., Jr. (2018). The economics and regulation of PRP in the evolving field of orthopedic biologics. *Current Reviews in Musculoskeletal Medicine, 11,* 558–565. https://doi.org/10.1007/s12178-018-9514-z

Kon, E., Di Matteo, B., Delgado, D., Cole, B. J., Dorotei, A., Dragoo, J. L., & Magalon, J. (2020). Platelet-rich plasma for the treatment of knee osteoarthritis: an expert opinion and proposal for a novel classification and coding system. *Expert Opinion on Biological Therapy*, 1–14. https://doi.org/10.1080/14712598.2020.1798925

Liebig, B. E., Kisiday, J. D., Bahney, C. S., Ehrhart, N. P., & Goodrich, L. R. (2020). The platelet-rich plasma and mesenchymal stem cell milieu: a review of therapeutic effects on bone healing. *Journal of Orthopaedic Research.* https://doi.org/10.1002/jor.24786

Liu, X., et al. (2019). BMSC transplantation aggravates inflammation, oxidative stress, and fibrosis and impairs skeletal muscle regeneration. *Frontiers in Physiology, 10,* 87. https://doi.org/10.3389/fphys.2019.00087

Scully, D., & Matsakas, A. (2019). Current insights into the potential misuse of platelet-based applications for doping in sports. *International Journal of Sports Medicine, 40,* 427–433. https://doi.org/10.1055/a-0884-0734

Stafford 2nd, C. D., Colberg, R. E., & Garrett, H. (2020). Orthobiologics in Elbow Injuries. *Clinics in Sports Medicine, 39*(3), 717–732. https://doi.org/10.1016/j.csm.2020.02.008.

Zhou, Q., Cai, Y., Jiang, Y., & Lin, X. (2020a). Exosomes in osteoarthritis and cartilage injury: advanced development and potential therapeutic strategies. *International Journal of Biological Sciences, 16*(11), 1811–1820. https://doi.org/10.7150/ijbs.41637

Zhou, Q. F., Cai, Y. Z., & Lin, X. J. (2020b). The dual character of exosomes in osteoarthritis: antagonists and therapeutic agents. *Acta Biomaterialia, 105*, 15–25. https://doi.org/10.1016/j.actbio.2020.01.040

Dietmar W. Hutmacher is a biomedical engineer, an educator, an inventor, and a creator of new intellectual property opportunities. He is committed to fostering transformative research and pedagogical innovation as well as programs that create an entrepreneurial mindset amongst faculty and students. He directs the Centre for Regenerative Medicine and the, a interdisciplinary team of researchers including engineers, cell biologists, polymer chemists, clinicians, and veterinary surgeons. Prof Hutmacher is an internationally recognized leader in the fields of biomaterials, tissue engineering and regenerative medicine with expertise in commercialization. He has translated a bone tissue engineering concept from the laboratory through to clinical application involving in vitro experiments, preclinical studies and ultimately clinical trials. His recent research efforts have resulted in traditional scientific/academic outputs as well as pivotal commercialisation outcomes. In his leisure time he likes to play golf, walk on the beach and explore Australian wines.

Information Processing Technologies

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

B. Torgler (✉)
Centre for Behavioural Economics, Society and Technology (BEST), Queensland University of Technology, Brisbane, Australia
e-mail: benno.torgler@qut.edu.au

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 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.

---

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

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 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 & Baca, 2013a, 2013b). 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 & 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 & 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 & 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 & Pentland, 2004) while also measuring stress via variation in prosodic emphasis (Pentland, 2008). According to

---

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

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.

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 & 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 (Bartlett, 2006; Lapham & Bartlett, 1995; Mężyk & Unold, 2011; Novatchkov & Baca, 2013a, 2013b; Perl, 2001), with the first computerized analysis commercially available as early as 1971 (Lapham & 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).

---

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

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 & Whitfort, 2013; Perl & 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 (McCullagh & Whitfort, 2013; Rygula, 2003). 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 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 & 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 & Polak, 2000). Nonetheless, quantum computing is a newly emerging field with the potential to dramatically change the way scholars think about complexity (Rieffel & 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 & 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

---

[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.

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.

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

---

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

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 & Cook, 1995). Hence, although many sports fans may remember Carl Lewis's four gold medals from the 1984 Summer Olympics (100, 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.

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 & 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 & 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

---

[9] https://www.wimbledon.com/pdf/Championships2019_Prize_money.pdf.
[10] https://www.nytimes.com/1992/03/05/sports/alan-roth-74-dies-baseball-statistician.html.

Research, many professional sporting teams have begun investing heavily in analytics departments (Casals & 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 & 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 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 & 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 & 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 & 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

---

[11] https://www.ibm.com/blogs/cloud-archive/2016/01/australian-open-2016-streaming-social-sentiment-with-bluemix-hybrid-cloud/.

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 & 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 & 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 & 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 & 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 & Button, 2008). Yet despite this potential, many sports organizations still prescribe training processes based on experience and intuition (Passfield & 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 & 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 & 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 & 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 & 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 sensing 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" (Greenbaum, 2018; Loland, 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 & 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 (Downward & Dawson, 2000; Pawlowski, 2013; Rottenberg, 1956; Schreyer et al., 2016, 2017, 2018a, 2018b; Schreyer & 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 & 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 & 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 (De Vany,

2004; Frank, 2016). 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.

References

Aharony, N., Pan, W., Ip, C., Khayal, I., & Pentland, A. (2011). Social fMRI: Investigating and shaping social mechanisms in the real world. *Pervasive and Mobile Computing, 7*(6), 643–659.

Allen, N. D., Templon, J. R., McNally, P. S., Birnbaum, L., & Hammond, K. (2010). Statsmonkey: A data-driven sports narrative writer. In *2010 AAAI Fall Symposium Series*.

Arute, F., Arya, K., Babbush, R., Bacon, D., Bardin, J. C., Barends, R., et al. (2019). Quantum supremacy using a programmable superconducting processor. *Nature, 574*(7779), 505–510.

Barris, S., & Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine, 38*(12), 1025–1043.

Bartlett, R. (2006). Artificial intelligence in sports biomechanics: New dawn or false hope? *Journal of Sports Science & Medicine, 5*(4), 474–479.

Baughman, A. K., Bogdany, R., Harrison, B., O'Connell, B., Pearthree, H., Frankel, B., et al. (2016). IBM predicts cloud computing demand for sports tournaments. *Interfaces, 46*(1), 33–48.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science, 275*(5304), 1293–1295.

Boden, M. A. (2016). *AI: Its nature and future.* Oxford University Press.

Boyer, P. (2018). *Minds make societies: How cognition explains the world humans create.* Yale University Press.

Brouwers, J., De Bosscher, V., & Sotiriadou, P. (2012). An examination of the importance of performances in youth and junior competition as an indicator of later success in tennis. *Sport Management Review, 15*(4), 461–475.

Brynjolfsson, E., Hitt, L. M., & Kim, H. H. (2011). Strength in numbers: How does data-driven decision making affect firm performance?. SSRN 1819486.

Buszard, T., Reid, M., Masters, R., & Farrow, D. (2016). Scaling the equipment and play area in children's sport to improve motor skill acquisition: A systematic review. *Sports Medicine, 46*(6), 829–843.

Caravelli, J., & Jones, N. (2019). *Cyber security: Threats and responses for government and business.* Praeger.

Carling, C., Wright, C., Nelson, L. J., & Bradley, P. S. (2014). Comment on 'Performance analysis in football: A critical review and implications for future research'. *Journal of Sports Sciences, 32*(1), 2–7.

Casals, M., & Finch, C. F. (2017). Sports biostatistician: A critical member of all sports science and medicine teams for injury prevention. *Injury Prevention, 23*(6), 423–427.

Choudhury, T., & Pentland, A. (2004). Characterizing social networks using the sociometer. In *Proceedings of the North American Association of Computational Social and Organizational Science (NAACSOS).*

Downward, P., & Dawson, A. (2000). *The economics of professional team sports.* Routledge.

De Vany, A. S. (2004). *Hollywood economics: How extreme uncertainty shapes the film industry.* Routledge.

du Sautoy, M. (2019). *The creativity code: How AI is learning to write, paint, and think.* HarperCollins.

Eagle, N., & Greene, K. (2014). *Reality mining: Using big data to engineer a better world*. MIT Press.

Eagle, N., & Pentland, A. S. (2006). Reality mining: Sensing complex social systems. *Personal and Ubiquitous Computing, 10*(4), 255–268.

Feynman, R. P. (1982). Simulating physics with computers. *International Journal of Theoretical Physics, 21*(6), 467–488.

Frank, R. H., & Cook, P. J. (1995). *The winner-take-all society: Why the few at the top get so much more than the rest of us*. Free Press.

Frank, R. H. (2016). *Success and luck: Good fortune and the myth of meritocracy*. Princeton University Press.

Fullerton, H. S. (1910). The inside game: The science of baseball. *The American Magazine, 70*, 2–13.

Gardner, H., & Davis, K. (2013). *The app generation: How today's youth navigate identity, intimacy, and imagination in a digital world*. Yale University Press.

Gatica-Perez, D., McCowan, L., Zhang, D., & Bengio, S. (2005). Detecting group interest-level in meetings. In *IEEE International Conference on Acoustics, Speech, and Signal Processing, 2005, Proceedings (ICASSP'05)* (Vol. 1, pp. I–489). IEEE.

Gigerenzer, G. (2007). *Gut feelings: The intelligence of the unconscious.* Penguin.

Gladwell, M. (2013). *David and Goliath: Underdogs, misfits, and the art of battling giants.* Hachette UK.

Greenbaum, D. (2014). If you don't know where you are going, you might wind up someplace else: Incidental findings in recreational personal genomics. *American Journal of Bioethics, 14*(3), 12–14.

Greenbaum, D. (2018). Wuz you robbed? Concerns with using big data analytics in sports. *American Journal of Bioethics, 18*(6), 32–33.

Grow, L., & Grow, N. (2017). Protecting big data in the big leagues: Trade secrets in professional sports. *Washington and Lee Law Review, 74,* 1567–1622.

Guan, H., Zhong, T., He, H., Zhao, T., Xing, L., Zhang, Y., et al. (2019). A self-powered wearable sweat-evaporation-biosensing analyzer for building sports big data. *Nano Energy, 59,* 754–761.

Hutchins, B. (2016). 'We don't need no stinking smartphones!' Live stadium sports events, mediatization, and the non-use of mobile media. *Media, Culture and Society, 38*(3), 420–436.

Jordan, J. J., McAuliffe, K., & Warneken, F. (2014). Development of in-group favoritism in children's third-party punishment of selfishness. *Proceedings of the National Academy of Sciences, 111*(35), 12710–12715.

Juma, C. (2016). *Innovation and its enemies: Why people resist new technologies.* Oxford University Press.

Kahn, J. (2003). *Neural network prediction of NFL football games.* University of Wisconsin-Madison.

Knight, P., & Walmsley, I. (2019). UK national quantum technology programme. *Quantum Science and Technology, 4*(4), 040502.

Kovalchik, S. A., & Reid, M. (2017). Comparing matchplay characteristics and physical demands of junior and professional tennis athletes in the era of big data. *Journal of Sports Science & Medicine, 16*(4), 489.

Kurzweil, R. (1999). *The age of spiritual machine: When computers exceed human intelligence.* Penguin Books.

Kurzweil, R. (2012). *How to create a mind: The secret of human thought revealed.* Penguin Books.

Lapham, A. C., & Bartlett, R. M. (1995). The use of artificial intelligence in the analysis of sports performance: A review of applications in human gait analysis and future directions for sports biomechanics. *Journal of Sports Sciences, 13*(3), 229–237.

Link, D. (2018). *Data analytics in professional soccer. Performance analysis based on spatiotemporal tracking data.* Springer Vieweg.

Loland, S. (2018). Performance-enhancing drugs, sport, and the ideal of natural athletic performance. *American Journal of Bioethics, 18*(6), 8–15.

McCullagh, J., & Whitfort, T. (2013). An investigation into the application of artificial neural networks to the prediction of injuries in sport. *International Journal of Sport and Health Sciences, 7*(7), 356–360.

Memmert, D., & Rein, R. (2018). Match analysis, big data and tactics: Current trends in elite soccer. *German Journal of Sports Medicine/Deutsche Zeitschrift für Sportmedizin, 69*(3), 65–72.

Merkel, S., Schmidt, S., & Torgler, B. (2019). Optimism and positivity biases in performance appraisal ratings: Empirical evidence from professional soccer, Mimeo. WHU – Otto Beisheim School of Management.

Mężyk, E., & Unold, O. (2011). Machine learning approach to model sport training. *Computers in Human Behavior, 27*(5), 1499–1506.

Michael, K., & Miller, K. W. (2013). Big data: New opportunities and new challenges [guest editors' introduction]. *Computer, 46*(6), 22–24.

Morgulev, E., Azar, O. H., & Lidor, R. (2018). Sports analytics and the big-data era. *International Journal of Data Science and Analytics, 5*(4), 213–222.

Muhammad, S., Tavakoli, A., Kurant, M., Pawłowski, M., Żukowski, M., & Bourennane, M. (2014). Quantum bidding in bridge. *Physical Review X, 4*(2), 021047.

Nevill, A., Atkinson, G., & Hughes, M. (2008). Twenty-five years of sport performance research in the Journal of Sports Sciences. *Journal of Sports Sciences, 26*(4), 413–426.

Novatchkov, H., & Baca, A. (2013a). Artificial intelligence in sports on the example of weight training. *Journal of Sports Science & Medicine, 12*(1), 27–37.

Novatchkov, H., & Baca, A. (2013b). Fuzzy logic in sports: A review and an illustrative case study in the field of strength training. *International Journal of Computer Applications, 71*(6), 8–14.

Page, T. (2015). Applications of wearable technology in elite sports. *Journal on Mobile Applications and Technologies, 2*(1), 1–15.

Passfield, L., & Hopker, J. G. (2017). A mine of information: Can sports analytics provide wisdom from your data? *International Journal of Sports Physiology and Performance, 12*(7), 851–855.

Peña, J. L., & Tuchette, H. (2012). A network theory analysis of football strategies. arXiv:1206.6904

Papić, V., Rogulj, N., & Pleština, V. (2009). Identification of sport talents using a web-oriented expert system with a fuzzy module. *Expert Systems with Applications, 36*(5), 8830–8838.

Pawlowski, T. (2013). Testing the uncertainty of outcome hypothesis in European professional football: A stated preference approach. *Journal of Sports Economics, 14*(4), 341–367.

Pentland, A. (2008). *Honest signals: How they shape our world*. MIT Press.

Pentland, A. (2014). *Social physics: How good ideas spread-the lessons from a new science.* Penguin Press.

Pentland, A., Lazer, D., Brewer, D., & Heibeck, T. (2009). Improving public health and medicine by use of reality mining. A whitepaper submitted for the Robert Wood Johnson Foundation.

Perl, J. (2001). Artificial neural networks in sports: New concepts and approaches. *International Journal of Performance Analysis in Sport, 1*(1), 106–121.

Perl, J., & Weber, K. (2004). A neural network approach to pattern learning in sport. *International Journal of Computer Science in Sport, 3*(1), 67–70.

Pohl, H., Holz, C., Reinicke, S., Wittmers, E., Killing, M., Kaefer, K., et al. (2012). Quantum games: Ball games without a ball, Mimeo. Hasso Plattner Institute, Potsdam, Germany.

Popkin, G. (2016). Scientists are close to building a quantum computer that can beat a conventional one. *Science News.*

Reep, C., & Benjamin, B. (1968). Skill and chance in association football. *Journal of the Royal Statistical Society. Series A (General), 131*(4), 581–585.

Rein, R., & Memmert, D. (2016). Big data and tactical analysis in elite soccer: Future challenges and opportunities for sports science. *SpringerPlus, 5*(1), 1–13.

Rieffel, E., & Polak, W. (2000). An introduction to quantum computing for non-physicists. *ACM Computing Surveys (CSUR), 32*(3), 300–335.

Rottenberg, S. (1956). The baseball players' labor market. *Journal of Political Economy, 64*(3), 242–258.

Rygula, I. (2003). Artificial neural networks as a tool of modeling of training loads. *IFAC Proceedings Volumes, 36*(15), 531–535

Savage, D. A., & Torgler, B. (2012). Nerves of steel? Stress, work performance and elite athletes. *Applied Economics, 44*(19), 2423–2435.

Schmidt, S. L., Torgler, B., & Jung, V. (2017). Perceived trade-off between education and sports career: Evidence from professional football. *Applied Economics, 49*(29), 2829–2850.

Schreyer, D., & Torgler, B. (2018). On the role of race outcome uncertainty in the TV demand for Formula 1 Grands Prix. *Journal of Sports Economics, 19*(2), 211–229.

Schreyer, D., Schmidt, S. L., & Torgler, B. (2016). Against all odds? Exploring the role of game outcome uncertainty in season ticket holders' stadium attendance demand. *Journal of Economic Psychology, 56,* 192–217.

Schreyer, D., Schmidt, S. L., & Torgler, B. (2017). Game outcome uncertainty and the demand for international football games: Evidence from the German TV market. *Journal of Media Economics, 30*(1), 31–45.

Schreyer, D., Schmidt, S. L., & Torgler, B. (2018a). Game outcome uncertainty in the English Premier League: Do German fans care? *Journal of Sports Economics, 19*(5), 625–644.

Schreyer, D., Schmidt, S. L., & Torgler, B. (2018b). Game outcome uncertainty and television audience demand: New evidence from German football. *German Economic Review, 19*(2), 140–161.

Silva, A. J., Costa, A. M., Oliveira, P. M., Reis, V. M., Saavedra, J., Perl, J., et al. (2007). The use of neural network technology to model swimming performance. *Journal of Sports Science & Medicine, 6*(1), 117.

Simon, H. A. (1956). Rational choice and the structure of the environment. *Psychological Review, 63*(2), 129–138.

Stopczynski, A., Sekara, V., Sapiezynski, P., Cuttone, A., Madsen, M. M., Larsen, J. E., et al. (2014). Measuring large-scale social networks with high resolution. *PLoS ONE, 9*(4), e95978.

Taha, T., & Thomas, S. G. (2003). Systems modelling of the relationship between training and performance. *Sports Medicine, 33*(14), 1061–1073.

Tajfel, H. (1970). Experiments in intergroup discrimination. *Scientific American, 223*(5), 96–103.

Thomas, G., Gade, R., Moeslund, T. B., Carr, P., & Hilton, A. (2017). Computer vision for sports: Current applications and research topics. *Computer Vision and Image Understanding, 159,* 3–18.

Torgler, B. (2019). Opportunities and challenges of portable biological, social, and behavioral sensing systems for the social sciences. In G. Foster (Ed.), *Biophysical measurement in experimental social science research* (pp. 197–224). Academic Press.

UK National Quantum Technologies Programme. (2015). National strategy for quantum technologies: A new era for the UK. Innovate UK and the Engineering and Physical Sciences Research Council.

van der Slikke, R. M., Bregman, D. J., Berger, M. A., De Witte, A. M., & Veeger, D. J. H. E. (2018). The future of classification in wheelchair sports: Can data science and technological advancement offer an alternative point of view? *International Journal of Sports Physiology and Performance, 13*(6), 742–749.

Verhagen, E. A., Clarsen, B., & Bahr, R. (2014). A peek into the future of sports medicine: The digital revolution has entered our pitch. *British Journal of Sports Medicine, 49*(9), 739–740.

Weber, G. M., Mandl, K. D., & Kohane, I. S. (2014). Finding the missing link for big biomedical data. *JAMA, 311*(24), 2479–2480.

Weiss, P. (1969). *Sport: A philosophical inquiry.* Arcturus Books.

West, G. B. (2017). *Scale: The universal laws of growth, innovation, sustainability, and the pace of life in organisms, cities, economies, and companies.* Penguin.

Zettler, P. J. (2009). Is it cheating to use cheetahs: The implications of technologically innovative prostheses for sports values and rules. *Boston University International Law Journal, 27,* 367–409.

Benno Torgler Ph.D., is a Professor of Economics at the Queensland University of Technology and the Centre for Behavioural Economics, Society and Technology and leads the program "Behavioural Economics of Non-Market Interactions" that covers the sub-programs Sportometrics, Sociometrics, Scientometrics, and Cliometrics. Besides a strong passion for doing research in the area of sportometrics, he has been carefully following the literature on AI for many years and cites AI pioneers such as Herbert Simon, Allen Newell, Marvin Minsky, and Seymour Papert as strong influences. In his free time, he loves to surf (although he is not particularly good at it) and exercise.

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.

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

C. Chase (✉)
MIT Sports Lab, Massachusetts Institute of Technology, Cambridge, MA, USA
e-mail: cchase@mit.edu

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 & Anguera, 2015), and analyzing NBA player shooting styles using body pose (Felsen & 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 & 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.

References

https://www.ibmbigdatahub.com/blog/taking-data-analytics-hoop.

https://www.nytimes.com/2017/09/07/sports/nfl-expands-use-of-chips-in-footballs-promising-data-trove.html.

https://www.geekwire.com/2019/seattle-seahawks-turn-amazon-web-services-new-cloud-deal-fuel-future-championships/.

https://www.wired.com/2015/10/robot-radiologists-are-going-to-start-analyzing-x-rays/.

https://www.si.com/mlb/2019/11/19/robot-umpires-automated-strike-zone.

https://www.ted.com/talks/rajiv_maheswaran_the_math_behind_basketball_s_wildest_moves/transcript.

https://www.espn.com/nfl/story/_/id/24445965/player-tracking-data-next-step-nfl-analytics-revolution.

https://www.technologyreview.com/s/600957/big-data-analysis-is-changing-the-nature-of-sports-science/.

https://www.forbes.com/sites/kristidosh/2019/08/06/nfl-renews-with-zebra-technologies-for-on-field-player-tracking-for-next-gen-stats/#1c04819c94ca.

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/.

https://theathletic.com/1235430/?source=twittersf.

https://www.businessinsider.com/nfl-using-ai-player-salaries-pro-football-focus-2019-7.

https://www.nbcnews.com/mach/science/how-ai-helping-sports-teams-scout-star-players-ncna882516.

https://www.zerohedge.com/news/2019-12-25/quants-are-taking-over-nfl.

https://news.mit.edu/2019/predicting-driving-personalities-1118.

https://news.mit.edu/2019/deeprole-ai-beat-humans-role-games-1120.

https://www.techworld.com/tech-innovation/digital-twins-of-athletes-next-frontier-for-sports-3777364/.

https://www.csail.mit.edu/news/put-any-person-any-pose.

https://www.ciodive.com/news/NFL-AWS-AI-ML-safety/568619/.

https://chbrown.github.io/kdd-2013-usb/kdd/p973.pdf.

https://news.sap.com/2018/10/executive-huddle-sap-helps-49ers-improve-operations-fan-experience/, https://www.forbes.com/sites/simonogus/2020/01/19/the-san-francisco-49ers-are-utilizing-big-data-at-levis-stadium-in-their-efforts-to-modernize-the-fan-expierience/#7603df95554d.

https://www.forbes.com/sites/davidramil/2020/01/13/miami-heat-innovation-with-data-leads-to-agreement-with-bucks/#ad5a91e7174a.

https://www.techrepublic.com/article/how-the-nfl-and-amazon-unleashed-next-gen-stats-to-grok-football-games/.

https://www.nba.com/clippers/clippers-introduce-revolutionary-technology-launch-clippers-courtvision-digital-viewing-experience.

https://www.forbes.com/sites/simonogus/2019/05/26/augmented-reality-options-by-second-spectrum-added-to-espn-app-for-nba-playoffs/#6a0ecbfa3db4.

https://www.sporttechie.com/intel-to-deploy-new-be-the-player-broadcast-feature-in-super-bowl-li-partners-with-patriots-qb-tom-brady/.

https://www.wsj.com/articles/the-future-of-sports-is-interactive-immersive-and-intense-11552827600.

http://gendershades.org/overview.html.

https://venturebeat.com/2018/12/21/researchers-expose-biases-in-datasets-used-to-train-ai-models/.

https://www.csail.mit.edu/news/ai-de-biases-algorithms.

https://www.csail.mit.edu/news/wapo-op-ed-how-regulate-ai-properly.

https://www.csail.mit.edu/news/better-fact-checking-fake-news.

https://www.csail.mit.edu/news/new-film-highlights-dangers-deepfakes-shaping-alternative-histories.

https://go.forrester.com/blogs/the-growing-legal-and-regulatory-implications-of-collecting-biometric-data/.

https://www.mintz.com/insights-center/viewpoints/2186/2017-12-athletes-and-their-biometric-data-who-owns-it-and-how-it.

Are all samples created equal? Boosting generative mdels via importance weighting. 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.

Bridgeman, L., Volino, M., Guillemaut, J.-Y., & Hilton, A. (2019). Multi-person 3D pose estimation and tracking in sports. In *The IEEE Conference on Computer Vision and Pattern Recognition (CVPR) Workshops*, June 2019.

Brooks, J., Kerr, M., & Guttag, J. (2016). Developing a data-driven player ranking in soccer using predictive model weights. In *KDD International Conference on Knowledge Discovery and Data Mining (KDD'16). Association for Computing Machinery* (pp. 49–55), New York, NY, USA. https://doi.org/10.1145/2939672.2939695

Cite as: arXiv:1406.2661 [stat.ML].

Digital twin https://en.wikipedia.org/wiki/Digital_twin.

Felsen, P., & Lucey, P. (2017). Body Shots: Analyzing shooting styles in the NBA using body pose. In *MIT Sloan Sports Analytics Conference,* Boston.

Felsen, P., Lucey, P., & Ganguly, S. (2018). Where will they go? Predicting fine-grained adversarial multi-agent motion using conditional variational autoencoders. In *The European Conference on Computer Vision (ECCV)* (pp. 732–747).

Grover, A., Song, J., Agarwal, A., Tran, K., Kapoor, A., Horvitz, E., & Ermon, S. (2019). Bias correction of learned generative models using likelihood-free importance weighting. arXiv:1906.09531 [stat.ML].

Gyarmati, L., & Anguera, X. (2015). Automatic extraction of the passing strategies of soccer teams. arXiv:1508.02171.

Hsieh, H.-Y., Chen, C.-Y., Wang, Y.-S., & Chuang, J. H. (2019). BasketballGAN: generating basketball play simulation through sketching. In *Proceedings of the 27th ACM International Conference on Multimedia (MM'19)*, 21–25 October 2019, Nice, France.

Karkazis, K., & Fishman, J. R. (2017). Tracking U.S. professional athletes: The ethics of biometric technologies. *The American Journal of Bioethics, 17*(1), 45–60. https://doi.org/10.1080/15265161.2016.1251633.

Le, H., Carr, P., Yue, Y., & Lucey, P. (2017). Data-driven ghosting using deep imitation learning. In *MIT Sloan Sports Analytics Conference.*

New data shows baseball managers when to replace the starting pitcher. https://phys.org/news/2014-02-baseball-pitcher.html.

Rossi, A., Pappalardo, L., Cintia, P., Iaia, F. M., Fernàndez, J., & Medina, D. (2018). Effective injury forecasting in soccer with GPS training data and machine learning. *PLoS ONE, 13*(7), e0201264. https://doi.org/10.1371/journal.pone.0201264.

Christina Chase is the Co-founder and Managing Director of the MIT Sports Lab, which helps professional sports teams, global brands, and organizations tackle challenges at the intersection of sports, data, and engineering. She is interested in how new sources of data will unearth revolutionary insights around the game, performance, training, and the future fan. She has been an entrepreneur, starting her first company at 18 years old, and an athlete, having trained at the US Olympic Training Center. Now at MIT, working with those at the forefront of research and sport, her intention is to make a broad impact on sport and even global health and wellness. She hopes this book, with such diverse contributors, may shine a light on the possibilities at the intersection of sports and technology.

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 determined by the mental state and psychological condition of the athlete (Raglin

M. Bartl (✉)
TAWNY and HYVE, Munich, Germany
e-mail: mb@michaelbartl.com

J. Füller
HYVE, Innsbruck University, Innsbruck, Austria
e-mail: johann.fueller@uibk.ac.at

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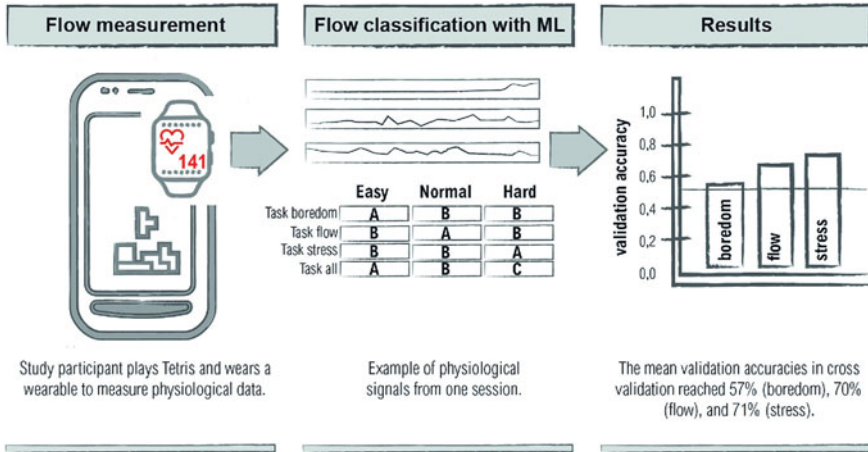
Fig. 1 Study overview for measuring flow (Maier et al. 2019)

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 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

Pretest to evaluate study structure
• Different wearables and the equipment for data collection are tested
• The right biathlon discipline and activity for the experiment is selected
• Athletes give general feedback on FLOW moments and the labelling options

Interviews with athletes before performance
• The athletes' emotional states before the experiment are valuated and the equipment is tested
• Interviews on FLOW experiences are conducted with the athletes

Experiment
• Athletes are equipped and perform their discipline and activity
• A checklist during the experiment supports a thorough and continuous data collection
• A film team documents and video tapes the experiment

Interviews and short questionnaire after performance
• A self-assessment and short questionnaire is conducted after the activity
• The labelling and rating is carried out using the documentation and video material

Data science process
• A systematic data analysis process is applied
• The results are reported to the athletes and to the whole team involved in the experiment

Fig. 2 Study design

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 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.
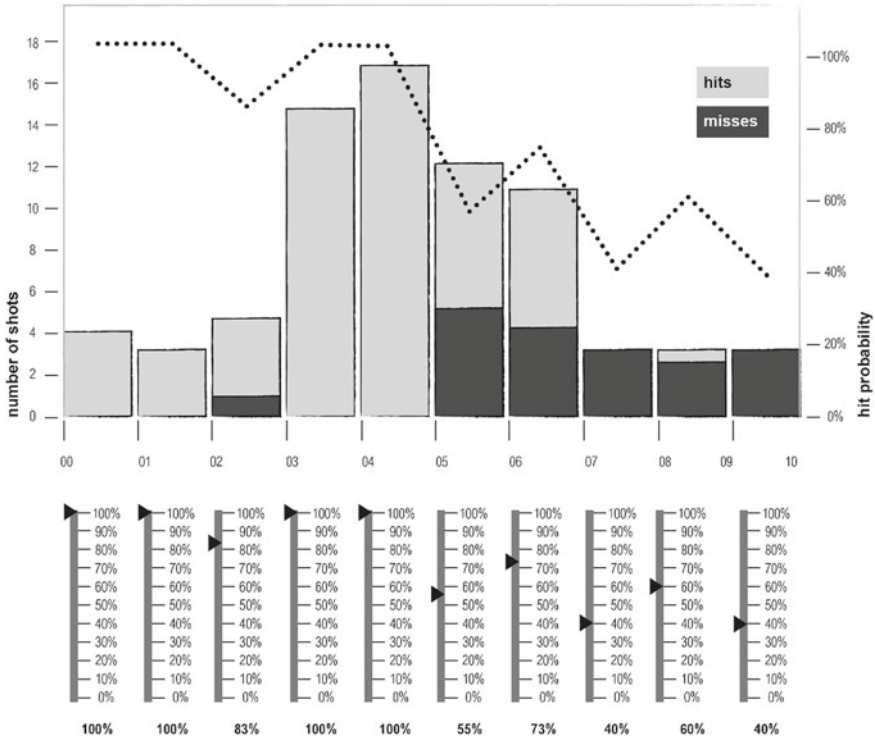
Fig. 3 Physiological pattern and hit probability

Based on 100 shots in competition mode, an average hit rate of 77% and over-all 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 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.
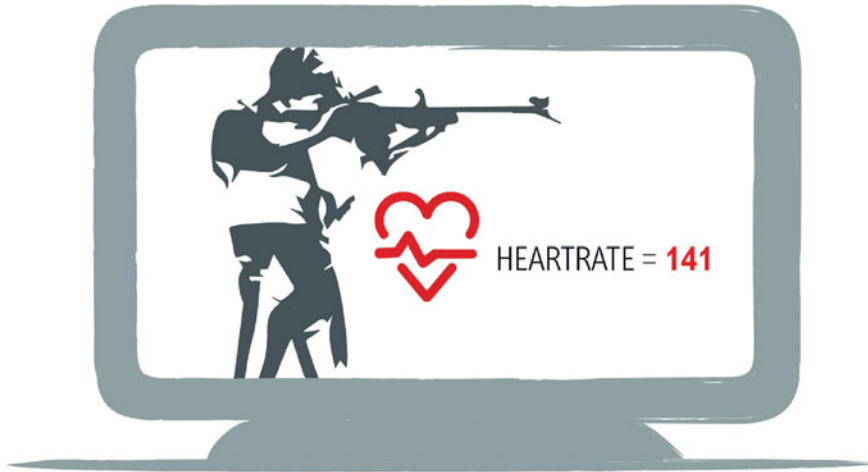
Fig. 4   Metadata in video. *Source* https://youtu.be/tiQwXrbwOQc

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.

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

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

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.

References

Bali, A. (2015). Physiological factors affecting sports performance. *International Journal of Physical Education, Sports and Health, 1*(6), 92–95.

Bartl, M. (2018). Das 4-Stufenmodell der emotionalen Intelligenz von Maschinen. *The Making-of Innovation E-Journal*. Retrieved from https://www.makingofinnovation.com.

Bartl M., Maier M., & Richter, D. (2017). Affective computing and the rise of emotionally intelligent products. In *The 2017 World Mass Customization and Personalization Conference.*

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York: Harper and Row.

Csikszentmihalyi, M., & Csikszentmihalyi, I. (1992). *Optimal experience: Psychological studies of flow in consciousness*. Cambridge University Press.

Csikszentmihalyi, M., & Jackson, S. (1999). *Flow in sports*. Champaign: Human Kinetics.

Harmat, L., et al. (2015). Physiological correlates of the flow experience during computer game playing. *International Journal of Psychophysiology, 97*(1), 1–7.

Hills, P., & Argyle, M. (2002). The Oxford happiness questionnaire: A compact scale for the measurement of psychological well-being. *Personality and Individual Differences, 33*, 1073–1082.

Keller, J., et al. (2011). Physiological aspects of flow experiences: Skills-demand-compatibility effects on heart rate variability and salivary cortisol. *Journal of Experimental Social Psychology, 47*(4), 849–852.

Link, D. (2018). Sports Analytics-wie aus (kommerziellen) Sportdaten neue Möglichkeiten für die Sportwissenschaft entstehen. *German Journal of Exercise and Sport Research, 48*,13–25. https://doi.org/10.1007/s12662-017-0487-7.

Maier, M., Bartl, M., & Richter D. (2017) The tawny project–flow measurement based on biofeedback to improve distributed innovation systems. In *The 15th International Open and User Innovation Conference.*

Maier, M., Marouane, C., & Elsner, D. (2019). DeepFlow: Detecting optimal user experience from physiological data using deep neural networks. In *International Conference on Autonomous Agents and Multiagent Systems.*

Maier, M., Elsner, D., Marouane, C., Zehnle, M., & Fuchs, C. (2019). DeepFlow: Detecting optimal user experience from physiological data using deep neural networks. In *International Joint Conference on Artificial Intelligence.*

Picard, R. (1997). *Affective computing.* Boston: MIT Press.

Raglin, J. S. (2001). Psychological factors in sport performance. *Sports Medicine*, *31*(12), 875–890.

Richter, D., & Bartl, M. (2018). Affective computing applied as a recipe recommender system. In C.M. Stützer, M. Welker & M.Egger (Eds.), *Computational social science in the age of big data* (pp. 379–396). Herbert von Halem Verlag Cologne.

Rheinberg, F., Vollmeyer, R., & Engeser, S. (2003). Die Erfassung des Flow-Erlebens. In J. Stiensmeier-Pelster & F. Rheinberg (Eds.), *Diagnostik von Selbstkonzept, Lernmotivation und Selbstregulation* (pp. 261-279). Göttingen: Hogrefe.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54*(6), 1063–1070.

Michael Bartl is Managing Director of the Emotion AI startup TAWNY and former CEO for HYVE, an innovation company creating new products and services for 70% of the German index companies and many international clients. He is also a research fellow of the Peter Pribilla Foundation, editor of the the E-Journal "The Making-of Innovation," and regular speaker at innovation and other industry conferences. As a sports enthusiast, Michael represented Germany at the recent European World Masters Athletics Championships in the decathlon and pole vaulting. His personal interest in training optimization fuels his interest in AI and technology in sports.

Johann Füller is a Professor for Innovation and Entrepreneurship at the Department of Strategic Management, Marketing, and Tourism at Innsbruck University and CEO of HYVE. He also initiated the InnCubator.at, the joint entrepreneurship center of Innsbruck University and Tyrolian Chamber of Commerce; as enthusiastic mountaineer, he also supervises the largest entrepreneurship festival on skies. His research interests are in the area of Artificial Intelligence, Open Innovation, Crowdsourcing, Corporate Entrepreneurship, Incubation, and Digitalization. Before his professorship, Johann was a Fellow at the NASA Tournament Lab at Harvard University and a visiting scholar and research affiliate at MIT Sloan School of Management.

Blockchain: From Fintech to the Future of Sport

Sandy Khaund

Abstract

In this chapter, Khaund provides 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 of networked computers that cooperate to validate transactions, blockchain

S. Khaund (✉)
Credenza, San Fransico, CA, USA
e-mail: psandyk@gmail.com

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, often referred to as "stablecoins." 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

Let's consider 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 microtrans-actions 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 mit-igated 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 technol-ogy 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.

Since the publication of the first edition of this book in 2020, more states in the USA have approved betting and both FanDuel and DraftKings enjoyed record betting revenues during the Super Bowl LVII in February 2023.

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. As of 2023, it's only 15 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.

Even in the years between the first and second editions of this text, new innovations have been introduced that have drastically improved these critical metrics. The most prominent set of innovations has been in Layer 2 solutions, which are designed to increase the throughput, latency, and scale of Ethereum by intermediating transactions off the Ethereum ("Layer 1"), batching them, and then relaying them to Ethereum to continue to benefit from Ethereum's robust decentralized security model. In addition, the Layer 1 Ethereum's core technology has made a landmark transition to an advanced algorithm called Proof-of-Stake (PoS) from

Proof-of-Work (PoW). PoS allows for a more efficient method to confirm consensus of transactions than the traditional PoW, which requires far more computers to confirm over a longer period of time. When coupled with a technique of selective data distribution known as sharding, Ethereum has dramatically improved transaction times and throughput. Progress is happening and will continue to happen.

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. In addition, blockchain will benefit from "Metcalfe's Law," which dictates that the power of a network is proportional the number of users on it. The crypto boom of 2017 brought the first wave of users and the NFT boom of 2021 brought another; if each new major product advancement is coupled to technology improvements, we will get better and better. But mass adoption won't happen overnight and there will need to be patience.

Plus, the sports world isn't quite ready for a lot of the ideas proffered in this chapter.

5   What About Even Further in the Future?

In the original edition of this text, I predicted that many of the developments described above would happen in five to ten years, if not sooner.

And that forecast remains accurate as some innovations such as memorabilia deeds are happening, while others are getting ever closer. Looking further out, the crystal ball can get a little hazy in determining exactly what the impact of blockchain is.

There are a number of reasons for this:

- While the blockchain has matured, some of the most important developments haven't yet happened; distractions like NFT collectibles draw attention away from blockchain's true utility. 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 still 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 Dinwiddie, 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 Founder and CEO of Credenza, a company building the future of digital rights management on the blockchain, providing universal real-time access to fan attributes, actions and assets and using this information to determine digital access He was formerly Vice President of Product at Ticketmaster, which he joined 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 and worked with Blockchain development for over eight years, 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.

M. Carlsson-Wall (✉)
Center for Sports and Business, Stockholm School of Economics, Stockholm, Sweden
e-mail: martin.carlsson-wall@hhs.se

B. Newland
Undergraduate Programs & Sport Management, Preston Robert Tisch Institute for Global Sport at New York University, New York, NY, USA
e-mail: bln2@nyu.edu

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 et al., 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 commercial? Yes, they are. However, commercial leagues also
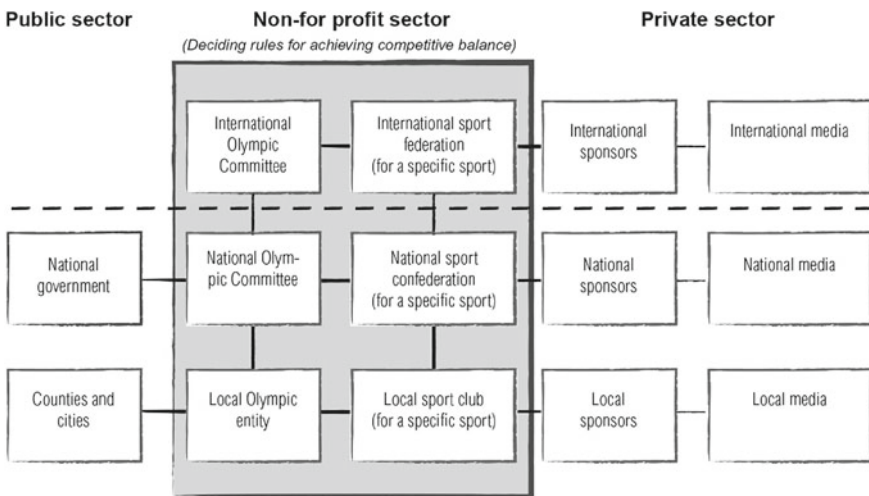
Fig. 1 Simplified illustration of the global sport system

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:

> 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

---

[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	Club and league management	Ecosystem development
1XBit	Bandwagon	Beat
Betdemocracy	Blocksport	Cryptosport
Bethereum	Chiliz/Socios.com	Mediar
Bitplay	Dapper Labs	Olympia
Blinkpool	Fantastec	Plair
BlitzPredict	Football Fan App	Ronaldinho Soccer Coin
Blok Sports	Footies	Setteo
Decent.bet	Instant Sponsor	Sportcash One
FansUnite	StarGraph	Tookens
Fantasy Sports Betting	Tixico	Womprotocol
Herocoin	United Fans	
My Ether Sports	WisFans	
Pay2Play		
Ryu Games		**Collectibles and memorabilia**
Stox		Animoca Brands
Unikoingold	**Health and personal integrity**	Ex Sports Starz
Wagerr	Lympo	Gamedex
ZenSports	PeersPoint	Pro Exp Media
	PlayMaker Chain	Stryking
Fantasy sport	Revvo	
Digital Fantasy Sports	Spobi	
FNTC Sports	Sweatcoin	
FootballCoin		**Talent investment and crowdfunding**
No Limit Coin		Globatalent
Pokersports		Jetcoin
Protoblock		Netscouters
Rankingball		SportyCo
Strykz		

"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 cat-
egory, 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 physi-
cal 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 Sweat-
coin (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 part-
nership 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. Ani
mocabrands.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 for-
mal partnership with Bayern München. In 2019, Stryking.io was acquired by Ani
mocabrands.com. EX Sports (www.ex-sports.io) focuses on martial arts with part-
nerships 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; Garud et al., 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.
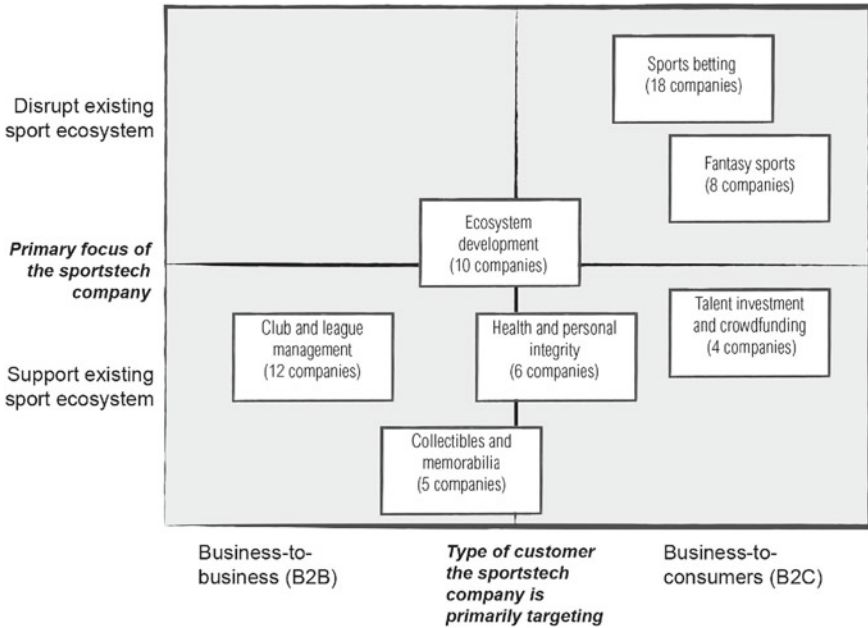
Fig. 2 The emerging blockchain and sport landscape

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 Dec ent.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 busi ness 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 associ ated 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 com pany 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 alterna tive 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 portfo lio 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.

References

Anderson, J., Håkansson, H., & Johanson, J. (1994). Dyadic business relationships within a business network context. *Journal of Marketing, 58*(1), 1–15.

Baraldi, E., & Strömsten, T. (2009). Controlling and combining resources in networks—From Uppsala to Stanford, and back again: The case of a biotech innovation. *Industrial Marketing Management, 38*(5), 541–552.

Davies, S. T., Singh, S., Maher, S., Kalfon, P. A., Maslova, A., Dellea, D., & Rouet, R. (2019). *How blockchain and its applications can help grow the sports industry?* Report by PwC as part of the #Ambitions 2024 Initiative.

Garud, R., Kumaraswamy, A., & Karnöe, P. (2010). Path dependency or path creation? *Journal of Management Studies, 47*(4), 760–774.

Sensor Tower. (2020). *Top charts: iTunes.* https://www.sensortower.com.

Smith, A., & Stewart, B. (2010). The special features of sport: a critical revisit. *Sport Management Review, 13,* 1–13.

Stewart, B., & Smith, A. (1999). The special features of sport. *Annals of Leisure Research, 2*(1), 87–99.

Zander, I., & Zander, U. (2005). The inside track: On the important (but neglected) role of customers in the resource-based view of strategy and firm growth. *Journal of Management Studies, 42*(8), 1519–1548.

Martin Carlsson-Wall is the Director for the Center for Sports and Business and Professor at the Stockholm School of Economics. His research is focused on the management of sport organizations and how innovation processes within sport need to carefully balance commercial and non-commercial ideals. In his free time, he enjoys running and hiking with his wife and two kids.

Brianna Newland is Assistant Dean, Division of Applied Undergraduate Studies & Clinical Professor, Tisch Institute at New York University (NYU). Her research is focused on sport development, events, and tourism. Prior to working at NYU, she worked at the University of Delaware, Victoria University in Australia, and the University of Texas at Austin. In her free time, she has competed in three Ironman races and is currently training for her next race. Her section, focused on blockchain technology, is inspired by her interest in the consumer experience as it relates to mass participation sport.

Blockchain Innovation in Sports Economies

Jason Potts, Stuart Thomas, and Kieran Tierney

Abstract

In this chapter, Potts, Thomas and Tierney consider sports as an economy and the impact of innovation, blockchain technology and its applications, on truth and trust in sports and business models and opportunities. They dedicate space and time to several of blockchains' potential applications in sports—NFTs, DAOs, and web3 chief among them. Finally, with blockchain technology as their new foundation, they imagine the future of sports economies.

1   A Sport is an Economy

A sport, abstractly considered, is a group of people who come together to interact in particular ways with specific technologies according to a specific set of rules (Thomas & Potts, 2015). In this sense, a sport is an economy made of economic agents (players, fans, clubs, leagues) interacting according to a set of rules and governing institutions, with specific technologies and capital. Sports economies generate private value and public revenue, produce positive social externalities in health and community, create jobs, drive investment, engage fans, and have regional and national impact. The focus of this chapter is on innovation in sport

J. Potts (✉) · S. Thomas
RMIT University Blockchain Innovation Hub, Melbourne, Australia
e-mail: jason.potts@rmit.edu.au

S. Thomas
e-mail: stuart.thomas@rmit.edu.au

K. Tierney
RMIT University School of Economics, Finance and Marketing, Melbourne, Australia
e-mail: kieran.tierney@rmit.edu.au

as an economy. Innovation occurs when technologies, such as the introduction of blockchain and the associated applications, or rules that govern them change (Potts & Rattan, 2016).

First, we examine the agents, rules, and technologies of sport. The people in a sport include players, fans, volunteers, and workers involved in sports production, makers of sports equipment and merchandise, members of leagues and governing bodies, the media, and others. Sports require rules; the rules of a sport specify the limits and conditions of play, what moves or strategies are permissible, and the consequences of particular actions or outcomes. Systems of rules are costly to monitor, maintain, and enforce but are essential for the health and functioning of the sports economy. The "technology" is seen as the sporting equipment, whether its bats, balls, skis, bicycles, kayaks, or America's Cup yachts and Formula One racing cars; even athletic clothing is included. It is also the technology of the field or arena, and of the broadcast. But it also includes the administrative technology of the clubs and the leagues, of registration of athletes and the technologies of coaching, performance management, certification, and doping tests.

Blockchain technologies, which are fundamentally a new technical architecture for the internet, are a relatively recent and somewhat-hyped innovation that has little obvious disruptive effect on sports. For example, blockchains do not advance equipment engineering, athletic performance, or gameplay, nor offer any obvious advantage to hosting and watching sports. But blockchains and web3 technologies are poised to revolutionize the business of sports by fundamentally disrupting the underlying economic "primitives" of sports, the trusted agreements between parties.

Here, some background on blockchains and terminology is useful. Blockchains are decentralized digital ledgers, which were first introduced in 2009 as the technology behind cryptocurrencies. Blockchains allow information to be stored in a secure, immutable, and transparent manner. A blockchain is a protocol that uses a network of computers to verify and validate transactions and store them in blocks. Each "block" is linked to the previous block forming a "chain." A blockchain enables common knowledge about the state of a system and records information in a digital ledger without requiring permission from any intermediary or supervisory party. This allows new economic primitives, which can be used to construct new digital economies including smart contracts (self-executing programs running on blockchains), oracles, and the Internet of Things (discussed later in this chapter) that bring real-world data into verifiably unique digital assets like smart contracts, crypto tokens, and non-fungible tokens (NFTs). Digital assets include credentials, tickets, artwork, and video images. Decentralized autonomous organizations (DAOs) are resident on blockchains and can hold assets and enact community governance using agreed protocols, voting, and smart contracts.

Blockchains underpin a supercluster of new digital technologies–broadly called web3–that includes cloud computing, generative AI, low latency wireless, and augmented and virtual reality. These building blocks work together to create new digitally-native economic institutions that are the foundational infrastructure for building new, digital economies. As secure immutable ledgers, blockchains keep

track of mutually agreed economic facts about ownership and transactions. Crypto tokens enable the digital representation of money and other assets that can be created, controlled, traded, and otherwise used on the Internet. Smart contracts and digital signatures enable the building of new economies out of agreements, exchanges, and promises. This supercluster of innovative digital technologies lowers the cost of building digital economies and increases the scope of their design possibilities.

2   Truth and Trust in Sports

Blockchains disrupt and add new value to the sports economy as technologies of trust and truth. Sports involve people playing or interacting according to rules. Rule following, compliance, scoring, and timing is essential to determining the outcomes of a sport. Verifiable rule-following and compliance builds trust in the economic process and establishes the truth about what happened. The domain of trust and truth includes who is allowed to be a player; integrity of in-game play and performance; coordination of leagues, clubs, and events; and so on. The institutional legitimacy of the sport, as well as its private enjoyment and economic value, is a direct function of the effectiveness of rules, in the sense of the "rules of the game" and the governance of the sport (Thomas & Tierney, 2021). Blockchains are a disruptive innovation in sports as economies because they substantially reduce the "cost of trust" in sports (Novak et al., 2018).

Blockchains help to maintain trust in professional sports by providing a transparent and secure way to record and verify data. Data can be recorded immutably on a blockchain, providing a high level of transparency and accountability to prevent cheating and maintain the integrity of the game. Blockchains can also be used to securely track and verify transactions related to professional sports, such as ticket and merchandise sales, providing authentication of purchases to prevent fraud, scalping, and so on.

Doping and cheating have long troubled sports. Doping is costly to eradicate due to the considerable incentives to engage in it, especially if there is a reason to expect that other players are also cheating (Mohan & Hazari, 2016). Mohan (2019) proposed that blockchains can support incentive systems to induce players to truthfully reveal doping or cheating activities at the level of the event. This might not solve problems at the individual level, but it does provide a mechanism to reveal and respond to cheating in the overall sports economy.

Blockchain technology can support low-cost athlete certification and registration by providing a secure and tamper-proof way to store and track identity and credentials (such as licenses and registrations) and ensure eligibility to participate in the competition. Athletes' medical records, drug testing results, training records, and other relevant information can also be stored on a blockchain where it can be easily accessed and verified by sports organizations and regulators and ensure that athletes are competing legitimately, fairly, and safely.

There are, of course, concerns with introducing these technologies. For players, the main concerns related to blockchain technology are the privacy and security of their personal information. The development of privacy technologies on blockchains such as zero-knowledge proofs will be necessary to safely implement this technology. For fans, the main issue related to blockchain technology in professional sports is accessibility. While blockchain-based systems provide transparency and accountability, they can also be complex and difficult for non-technical users to understand. The user experience will need to improve and education will be necessary for large-scale adoption into sports.

3   New Sports Business Models Using NFTs

One of the most disruptive uses of blockchain technology in sports is Non-Fungible Tokens (NFTs), which can be used in different ways to create value in sports economies. NFTs stored on a blockchain are digitally unique assets that are impossible to duplicate. This feature has created a new market for digital art, collectibles, and other unique items that can be bought and sold like any other asset. A NFT is not substitutable with other tokens because of the specificity and verifiable uniqueness of its attached information. NFTs have a wide range of potential applications including, but not limited to, ticketing, unique digital assets, and merchandise; in this section, we explore these and more.

A NFT can work as a ticket for entry into an event (the attached information could be a QR code, for instance). A ticket provides access rights, in part, because it can be transferred to another person. NFT-based tickets can also be programmed to prevent scalping. Once used, a ticket also provides proof of attendance and can facilitate direct outreach to fans for "airdrops" of rewards and perks.

NFTs allow fans to own and trade unique digital assets related to their favorite sports teams and players. For example, a NFT could contain verifiably scarce content such as video of match highlights or limited edition player photos or messages; it functions, therefore, as a verifiably authentic and unique collectible. Simple digital content can be easily copied and reproduced, but NFTs solve this problem by encoding digital scarcity (uniqueness) and the capacity to store large amounts of digital information. A NFT can also function as a content delivery system between players and fans.

NFTs can create a platform for the delivery of richer context and experiences and can produce a more loyal, engaged fan base with a vested interest in the success of the team or league. NFTs' capabilities extend to fan engagement through permissioned access—stadium passes, access to clubs and private events, social networking and other forms of fan engagement. One of the most exciting, albeit still experimental, uses of NFTs are "fan-controlled sports" in which token ownership enables fans to participate in sports governance (Schmidt & Flegr, 2023). Highly personalized P2P channels enable much greater price and market discrimination than is possible in the mass-market or broadcast era of engagement. This

can be pushed as far as community ownership or partial governance rights that accrue to holders of particular NFTs (discussed when we consider DAO models below).

NFTs can be a new direct marketing channel between sports sponsors and fans. In Decentralized Finance (DeFi), platforms "airdrop" tokens to token holders in return for doing things that benefit the community, like particular types of transactions or voting on rules and protocols. Airdrops are a powerful incentive for community engagement. Available only to community members, they are rarely announced in advance to prevent them from being "gamed." The expectation of future airdrops incentivizes existing NFT holders to engage with the chain. The same mechanism can also be harnessed with NFTs as fan tokens; sponsors, teams, leagues, and athletes could reward highly engaged fans with airdrops of digital merchandise, preferential ticket pricing, or special access to players or events. For example, fans could earn NFTs for attending games, buying merchandise, or engaging with their favorite team or athlete on social media. The NFTs could then be used to purchase exclusive merchandise or experiences. NFT platforms would then facilitate both new revenue streams and new ways to directly engage with the community.

NFTs are not just for sports fans; they can also facilitate new forms of contracting between players and leagues. A player contract could specify and automate in-game performance bonuses, measured by telemetry from players or gear. This can be done without blockchain, but the problem is the credible enforcement of agreements. By linking oracle data directly into smart contracts, on players' key addresses, payments can be automatically made upon achievement of pre-contracted performance metrics or milestones. These bonuses could even be a tradable right, enabling players to monetize their performance on a secondary market.

As a tradable right, a NFT can be transferred on a digital exchange. If that tradeable right is restricted, or "soul-bound" as this limit is called on the Ethereum blockchain (Weyl et al., 2022), then these NFTs function as a verifiably unique digital identity. This is incredibly useful for credentials that need validation–such as for licenses or registration, medical clearances, selection qualifications, etc. The information loaded on the NFT can refer to historical performance, provide certification of skills for entry into tournaments, and store medical tests proving fitness and drug status.

Overall, NFTs can create new business opportunities for sports by enabling the creation and sale of unique digital assets, ticketing, and merchandise; more complex and incentivized fan engagement; and new revenue streams. NFTs can also enhance the integrity and reputation of the sport and help brand-building and sponsorship opportunities. They offer a new and innovative way for sports to connect with their fans and generate revenue.

4 Sports Data Oracles

Smart contracts use code that lives on blockchains to automate and enforce the terms of an agreement. They are computer programs designed to facilitate the negotiation, verification, enforcement, and execution of an agreement without the need for intermediaries or trusted third parties. They automate (i.e. they are "smart") conditional pre-agreed activities (i.e. they are "contracts"), like making payments in tokens to a specified address if a particular input is fed into the smart contract. Smart contracts can also interact with the real world when connected to an "oracle"—a source of data that enables a smart contract to execute a pre-specified action.

Oracles are third-party services or devices that provide data to a blockchain. They are often referred to as the "Internet of Things" (IoT) and are data-collecting devices that connect directly to the internet to capture and feed-in streams of data. These data can be used to trigger smart contracts, allowing the contracts to "interact" with real-world events and information. Oracles are particularly important for blockchain applications that rely on external data sources, such as weather conditions or stock prices. Oracles bring secure and reliable data onto the blockchain, making it available to smart contracts and other blockchain applications.

Smart contracts live on-chain, but oracles connect those blockchains to the external world of events and, thereby, enable an economy to form that exists both on-chain and off-chain (i.e., in the real world). The power of smart contracts combined with oracles creates new architecture and business models for sports data.

Sports generate a huge amount of data. Increasingly, that data is captured through direct player or equipment telemetry, and faster manual capture of other information; but, in most cases, it is still difficult to capture the full economic value of data owing to unclear ownership or property rights, privacy considerations, costly negotiation, and transactions to exchange rights. Generally, the data is implicitly claimed by the people (or devices) who capture it, e.g., the cameras in the stadium or by those who can effectively defend the negotiated rights to the first sale of the data. Professional codes often have explicit or implied rights to data ownership, but there may be no or few rights in amateur or community sports. The conventional use of sports data is for internal business or technical analysis, but increasingly, data holders are seeking ways to monetize it through broadcast rights, technical analysis services, and tokenization.

Captured data streams are valuable as oracles that feed into smart contracts. Sports data oracles present a new realm of revenue generation opportunities by building infrastructure to capture sports data. Data oracles become primitives for building new generations of products and services. On the sports production side, oracles can feed into tactical analytics and player incentives. On the sponsor side, oracles can feed into promotions and games, including parallel augmented or virtual reality games generated by the data feeds from the real-world physical game. For sports fans, oracles can feed into NFTs that register proof of attendance or capture collectible sports moments and can facilitate "play" directly in "digital twins" of the real-world game.

Data oracles, when coupled with smart contract-based platforms, can also feed secure prediction markets or sports betting. Smart contracts automate the betting process—ensuring that all bets are fair and transparent and that payouts are immediate upon validated oracle input. This reduces the risk of fraud and increases trust in betting. It also enables sports regulation and public governance to be built directly into betting platforms, rather than relying on costly (and corruptible) agency oversight.

There are, of course, challenges with the creation of new data oracles, including privacy conditions, the ethics of responsible data capture and use, data permissions, security, and reuse. In the corporate model of sports, the implied structure of data ownership and contracting is between the individual (e.g., player or fan) and the entity that owns or governs the sport. With blockchain, community or collective ownership of data, through trusts or DAOs could be possible. Of course, this could exist without blockchains; for example, by setting up a private company to execute the governing wishes of the community and establish contracts with counterparties that value the data. But, high setup and transaction costs relative to the value of the data, make this uneconomic. Because blockchains lower the cost of transaction governance considerably, new possibilities for data ownership and use arise. An interesting application of this model is to treat the data generated by the sport as collectively owned—by players, league, and fans—and to preference its use for public or charitable purposes. Many sports clubs seek to serve the local community or to engage in charitable activities. Blockchain enables donating data or using certain data to support or report on the outcomes of funding programs for grassroots sports.

While sports data is generally perceived as less valuable than financial market data, for example, it still needs to be secure. Blockchains can provide security for sports data by decentralizing the data across a distributed network, which helps prevent data breaches, fraud, and other security threats.

5   Organizing Sport

Professional sports tend to be organized around leagues, which govern the rules and conduct of franchises that organize competition. This is not only true of team sports like football or hockey but of athletic franchises like triathlon or gymnastics, which are governed by associations. These are all corporate entities, variously profit or non-profit. Amateur sports franchises tend to be not-for-profit clubs but often have a corporate form for administrative purposes—to establish ownership, lease club buildings and fields, serve as a counterparty for liability and insurance, and hold a bank account for operational payments. These administrative frameworks and legal structures are necessary to govern the sport as an economic entity. For the past hundred or so years, during the rise of professional sports and the development of the vast global sports industry, the organizations that administer these corporate entities have remained largely unchanged.

Smart contracts bring a radical innovation in sports governance and administration with the possibility of using decentralized autonomous organizations (DAOs) for sports governance. DAOs are organizations "run" by smart contracts on a blockchain, rather than by traditional hierarchical structures of people. DAOs allow people to come together and pool resources to achieve a common goal without the need for a centralized authority. Members of a DAO have voting rights, which allows them to make decisions collectively about how to allocate resources and manage the organization. This is a digitally native economic organization—an entity that can own and control digital assets and make low-cost collective decisions about the use of assets through token-controlled governance and deployment of smart contracts.

DAOs can fit into modern sports in different ways. The most obvious is for a DAO, as an investor syndicate, to buy and own a sports club and use token voting for governance. This is already occurring with some minor league football clubs, creating new challenges and opportunities for management, fan engagement, and marketing (Schmidt and Flegr, 2023).

DAOs could be used to solve more complex collective action problems in sports governance. Sports leagues and associations, conventionally a high-level body that administers and governs the sport, are obvious candidates to move to blockchains because of the opportunities for personal gain and corruption that exist at that level. Community-based, token-governed voting and governance would facilitate participation and decisions to admit new members or exclude existing ones. DAOs could modify or change rules or provide rulings on disputes by using distributed court systems like Kleros. Additionally, DAO technology could change the way that sports are financed by enabling the issuance of tokens that grant specific rights such as claims on future revenue, access to data, and decision-making.

Perhaps the highest value use of DAOs in sports is in the vast domain of amateur or community sports; often, the corporate model of administration is so costly and burdensome that it can challenge viability. In addition to lowering the costs of governance and administration through the use of smart contracts and storing certifications, background checks, training schedules, etc., DAOs offer a multitude of opportunities for governance, financing, and volunteering.

DAOs can be used in grass-roots clubs to create a decentralized governance model that allows all members to have a say in the decision-making process and speed up voting on issues like events or the selection of coaches and team captains. By allowing all members to have a voice, DAOs facilitate a stronger sense of identity and engagement in the community. DAOs can also create a transparent and efficient fundraising system for local clubs that ensures funds benefit the entire community.

NFT-based credentials can be transferred between clubs or sporting codes (like a permanent record) to reduce the need for checks-upon-checks, thus minimizing hurdles to voluntary participation. Moreover, DAOs can be used to manage volunteers. Members can "bid in" their time and vote on how they should be deployed, for a more efficient volunteer management system.

There are disadvantages to DAOs, too. They can be complex to set up and they require new skills to run them. Some blockchain platforms can be slow and unsuited to time-sensitive decisions, so chain choice is critical. With the current early-stage DAO tooling, these may be significant hurdles in the short run; but, these are largely technical problems that should be soon resolved.

6 Gaming, Esports, and the Metaverse

Online gaming, especially multiplayer platform gaming and esports, is a rapidly developing web3 frontier. With the adoption of web3 technologies into web2 platforms, digital assets like virtual in-game currencies, avatar "skins" and their marketplaces, and web3 tooling for games development we see much wider engagement from users and fans. Emerging trends in metaverse platforms are leading to a growth in 3D virtual reality (VR) gaming that is shaping the future of esports (Kim and Kim, 2022). Platforms now support new esports with athletes competing in physically demanding, immersive VR tournaments while the audience engages with players or even places bets in real time (Cranmer et al., 2021).

These lines of development are converging into new digital economies, some of them entirely virtual, and players are controlling innovations in gameplay and design and rights over assets created in-game that can be further developed or traded (soon across games). Our opening to this chapter emphasized that sports are economies. Gaming esports is at the frontier of building new economies inside the digital realm.

As markets though, gaming and esports can be viewed as an ecosystem of interdependent actors including players, designers, promoters, and even governance functions, where (so far) the technology platform owners have wielded regulatory power through licensing, game updates, deletions, etc. (Peng et al., 2020). There has been a lack of independent (i.e. participatory) governance resulting in a fragmented regulatory system; the most powerful actors get to shape institutions to service their agendas and risk a lack of "legitimacy" for players and fans. Just like "real" economies, game-economies become dysfunctional when too much power is concentrated. There is an important role in game design, as with economic policy, to build institutions that maintain competitiveness and limit concentrations of power (Thomas & Tierney, 2021). Consequently, there is a need for new institutions to coordinate and govern this economy and to provide (among other things) secure identities for players, access rights and exchanges for in-game tokens and assets, rule monitoring and enforcement, fair running of tournaments, dispute resolution, and so on.

Blockchain technologies can be used to create secure and transparent in-game economies for in-game assets, such as virtual currencies and character attributes, that can work across games, leagues, and tournaments and across time. With assets stored on a blockchain, they become almost impossible to duplicate or counterfeit. DAOs can govern the distribution of these assets, ensuring that they are

distributed and traded between players. Good tokenomic design enables in-game digital economies to thrive by ensuring that economies do not suffer destructive inflation or deflation or otherwise inhibit incentives to fun and interesting game-play.

Finally, a growing phenomenon in esports is the shaping of local esports economies through regional tournaments (McCauley et al., 2020). DAOs support decentralized tournaments run by the players themselves; this can create a more democratic and transparent system for esports tournaments wherein the players, and even the fans, can have a say in how the tournament is run and avert the risk of distorted production of in-game assets and unfair distributions that ruin the enjoyment or competitiveness of games. Blockchains can be used to create a tamper-proof system for anti-cheating in e-gaming. The results of games and matches can be stored on a blockchain, making them impossible to alter or delete; in turn, this will enhance trust in the e-gaming ecosystem and prevent cheating.

7   The Future of (Digital) Sports Economies

Blockchain technology is an important foundational element in a supercluster of advanced digital computing technologies—including artificial intelligence (AI) and augmented and virtual realities—that are disrupting many industries; and sport is not immune. AI has been developing since the 1960s but has reached a watershed moment in early 2023. Augmented and virtual reality technologies are transforming the fan and player experience by allowing fans to engage with sports in new and immersive ways. For instance, we predict that virtual reality (VR) and immersive technologies in esports will influence the digitization and modification of physical sports by facilitating fan engagement during the game. Fan engagement through VR in training sessions, for example, will allow fans to earn team-related NFTs or coaching credentials while the club supports fan well-being.

Teams can open new income streams through NFTs, digital tokens, etc., allowing fans to invest in the team and gain rights to VR and digital access to train or contribute to the running of the team and club. The value of NFTs will, like any currency or stockholding, be subject to on-field team fortunes. Therefore, engaging "super-fans" by giving them input to team tactics and club voting rights will create a vested interest and engagement in an advanced form of "crowd-sourcing" thus allowing fans to contribute to on- and off-field performance that influences the value of their NFTs. That engagement can be built on data stored in, verified, or processed through blockchains.

Wearable technology, such as smartwatches, smart clothing, and fitness trackers, already provide athletes with real-time data about their performance and health to optimize training programs and prevent injuries; they also spit data out to provide a more engaging experience for viewing fans. AI can be used to analyze vast amounts of statistics and game footage and to provide insights into player and team performance. These AI algorithms can run on cloud data stored in distributed smart contracts. Blockchain is critical in this supercluster because it provides the

foundational layer of record keeping and data in a distributed open architecture (Lv et al., 2022); the other digital information computing technologies in the stack are built upon this foundation.

Finally, we predict that blockchain and AI will further modify the oversight of sports. We already see the use of basic digital in-game technology such as video assistant referees (VAR) in soccer or the decision review system (DRS) in cricket, which are valuable to the game but subject to human error or corruption. The incorporation of AI and machine learning technologies into sport kit or even player implants, supported by oracles will allow real-time data feeds analyzed by DAOs to make decisions that enhance the credibility of match oversight. In that way, blockchain technology is heading towards being the foundational technical and economic infrastructure for frontier digital innovation in the global sports economy.

References

Cranmer, E., Han, D., van Gisbergen, M., Jung, T. (2021). Esports matrix: Structuring the esports research agenda. *Computers in Human Behavior*, *117*, 106671.

Kim, H., Kim, S. (2022). The show must go on: Why Korea lost its first-mover advantage in Esports and how it can become a major player again. *Technological Forecasting and Social Change*, *179*, 121649.

Lv, C., Wang, Y., & Jin, C. (2022). The possibility of sports industry business model innovation based on blockchain technology: Evaluation of the innovation efficiency of listed sports companies. *PLoS ONE, 17*(1), e0262035.

McCauley, B., Tierney, K., & Tokbaeva, D. (2020). Shaping a regional offline eSports market: Understanding how Jonkoping, the 'City of DreamHack', takes the URL to IRL. *International Journal on Media Management, 22*(1), 30–48.

Mohan, V. (2019). On the use of blockchain-based mechanisms to tackle academic misconduct. *Research Policy, 48*(9), 103805.

Mohan, V., & Hazari, B. (2016). Cheating in contests: Anti-doping regulatory problems in sport. *Journal of Sports Economics, 17*(7), 736–747.

Novak, M., Davidson, S., Potts, J. (2018). The cost of trust: a pilot study. *Journal of British Blockchain Association.* https://doi.org/10.31585/jbba-1-2-(5)2018.

Peng, Q., Dickson, G., Scelles, N., Grix, J., Brannagan, P. (2020). Esports governance: Exploring stakeholder dynamics. *Sustainability, 12*(19), 8270–8285.

Potts, J., & Rattan, V. (2016). Sports innovation. *Innovation: Management, Policy & Practice, 18*(3), 233–237.

Schmidt, S., Flegr, S. (2023). Lessons on customer engagement from fan controlled football. *Harvard Business Review*, https://hbr.org/2023/03/lessons-on-customer-engagement-from-fan-controlled-football

Thomas, S., Tierney, K. (2021). Institutional dynamics in sports: how governance, rules and technology interact. In: *Behavioural Sports Economics*, pp. 78–96. Routledge, London

Thomas, S., & Potts, J. (2015). Industry sustainability under technological evolution: A case study of the overshooting hypothesis in sports. *Procedia Engineering, 112*, 562–567.

Weyl, E. G., Ohlhaver, P., Buterin, V. (2022). Decentralized society: Finding web3's soul. Available at SSRN https://ssrn.com/abstract=4105763

Jason Potts is a Professor of Economics at RMIT University and Co-director of the Blockchain Innovation Hub at RMIT. He is also a chief investigator on the ARC Centre of Excellence for Automated Decision-Making and Society. His research work is centred about the study of innovation and its institutional context in the theory of economic evolution. His work has studied sports innovation as models of open innovation. Jason is a keen mountain runner.

Stuart Thomas is an Associate Professor and Director of Education Development at RMIT Blockchain Innovation Hub. He is also the Director of Learning at RMIT Digital3. Stuart is an established university learning and teaching leader, program manager and administrator. His research work is centred on finance and governance, and recently has explored the origin of new sports. Stuart is a keen stand-up paddle boarder, former competitive cyclist and (from time to time) a volunteer sports administrator and advisor to amateur sporting bodies.

Kieran Tierney is Program Manager for the Postgraduate Marketing Programs and Senior Lecturer in Marketing at RMIT University in Melbourne, Australia. His research interests are at the intersection of Consumer Engagement, Services Branding and Brand Strategy with a particular focus on the co-creation of service brand meaning. He is a founding member of the eSports Research Network. Kieran is a keen hockey player.

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

B. Shields (✉)
Managerial Communications, MIT Sloan School of Management, Cambridge, MA, USA
e-mail: shieldsb@mit.edu

I. Rein
Communication Studies, Northwestern University, Evanston, IL, USA
e-mail: i-rein@northwestern.edu

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, the population density of cities presents an ongoing challenge. 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.
–   *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 line item on the balance sheet for 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 in society. Alternatively, if fans stay home to watch the game because it is more convenient, fan bases will weaken over time. The empty stadiums during the Covid-19 pandemic proved just how important it was to have fans in the stadium, both for the players on the field and the fans watching at home.

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 & Novy-Williams, 2019). Currently, teams play only 17 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 has seriously considered 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 the league ever 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, prior to the 2023 season, the average Major League Baseball game lasted more than three hours, which the newly introduced pitch clock set out to decrease. Meanwhile, the average Fortnite battle royale game lasts 15 minutes, which is 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 headed in the right direction with its Hundred cricket tournament. Following the successes of the Indian Premier League's Twenty20 format, they made 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 carries more risk. 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, once faced 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. Golf superstars Tiger Woods and Rory McIlroy also seem to understand the importance of new formats based on the announcement of TGL, an indoor golf league that is also a partnership with the PGA Tour. TGL's success is still to be determined, but it represents the type of innovative thinking that will be required in the future.

The changeover to adopt scarcity - both in terms of season length and formats - 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 FIFA World Cup. 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 developing 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 case of Formula 1) 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 college 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 playing 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. Inspired by in-season tournaments in European football, the

NBA has also introduced an in-season tournament to add interest and recharge their regular 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 some point in the 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, glasses, or other hardware) 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 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 installed 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 now offer 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 head coach 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 the 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 modern 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 these 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 (NBA on Wednesday nights, WWE on Fridays). It would not replace going to 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 urban demographic shifts, 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 three 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, home to SoFi Stadium, hosted the 2022 Super Bowl and will host 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.

A final potential model is focusing on a single venue, where all teams and athletes convene to compete. Upstart women's sports league Athletes Unlimited

plays its softball, basketball, and lacrosse seasons at one venue (though different areas are used for each sport). This is more cost effective and creates efficiencies for broadcasting the events. Fans who attend can also experience an action-packed schedule, not just one game.

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.

References

Ahmed, M. (2019). *Can the hundred save English cricket?* Financial Times. https://www.ft.com/content/c1178dcc-769d-11e9-be7d-6d846537acab.

Arnovitz, K. (2019). *Sources: NBA talks fewer games, in-season event*. ESPN. https://www.espn.com/nba/story/_/id/27059802/sources-nba-talks-fewer-games-season-event.

Associated Press. (2019). *MLB attendance down for 4th straight year*. ESPN. https://www.espn.com/mlb/story/_/id/26857513/mlb-attendance-4th-straight-year; Lacques, G. (2019). *Baseball's future: Declining attendance—and shrinking stadiums to match*. USA Today. https://www.usatoday.com/story/sports/mlb/2019/08/08/mlb-attendance-stadiums-future/1941614001.

Bogage, J. (2019). *'We're the evangelists on this': Why the Atlanta Falcons are selling $1.50 hot dogs*. The Washington Post. https://beta.washingtonpost.com/sports/2019/03/06/were-evangelists-this-why-atlanta-falcons-are-selling-hot-dogs/?noredirect=on.

Brown, D. (2019). *Possibility or pipe dream: How close are we to seeing flying cars?* USA Today. https://www.usatoday.com/story/tech/2019/11/04/flying-cars-uber-boeing-and-others-say-theyre-almost-ready/4069983002/.

Cialdini, R. B. (2004). The science of persuasion. *Scientific American*. https://www.scientificamerican.com/article/the-science-of-persuasion/.

Clarke, L. (2019). *The Rams' $5 Billion stadium complex is bigger than Disneyland. It might be perfect for L.A.* The Washington Post. https://www.washingtonpost.com/sports/the-rams-5-billion-stadium-is-bigger-than-disneyland-it-might-be-perfect-for-la/2019/01/26/7c393898-20c3-11e9-8e21-59a09ff1e2a1_story.html.

ESPN. (n.d.). http://www.espn.com/nfl/attendance/_/sort/homePct.

Fischer, B. (2019). *The more fun league: NFL aims for better fan experience*. Sports Business Daily. https://www.sportsbusinessdaily.com/Journal/Issues/2019/08/19/Leagues-and-Governing-Bodies/NFL-fan-experience.aspx.

Ginella, M. (2019). *NGF study finds golf participation rises for the first time in 14 years*. Golf Advisor. https://www.golfadvisor.com/articles/golf-participation-rises-ngf.

Greenstein, T. (2019). '*Have you ever wanted to host a tournament in your backyard?' Go inside the Tiny House next to the 14th Tee at Medinah Country Club*. Chicago Tribune. https://www.chicagotribune.com/sports/ct-bmw-championship-tiny-house-medinah-20190815-eandj424knebdprv3spxk5os3i-story.html.

Harding, X. (2019). *During NBA free agency, Twitter's most talked-about person wasn't even a player*. Fortune. https://fortune.com/2019/07/01/nba-news-free-agency-woj/.

Helin, K. (2019). *Shorter season? Shorter games? Tournaments? Adam Silver says NBA considering it all*. ProBasketballTalk. NBC Sports. https://nba.nbcsports.com/2019/04/13/shorter-season-shorter-games-tournaments-adam-silver-says-nba-considering-it-all/.

Johnson, S. (2018). *We tried out the new, Instagram-friendly Wndr Museum, now open in the west loop*. Chicago Tribune. https://www.chicagotribune.com/entertainment/museums/ct-ent-wndr-museum-chicago-instagram-0925-story.html.

Liverpool FC. (n.d.). *Official LFC Supporters Clubs*. https://www.liverpoolfc.com/fans/official-lfc-supporters-clubs.

McCaskill, S. (2019). *Tottenham hotspur stadium uses tech to offer new fan experiences and faster beer service*. Forbes. https://www.forbes.com/sites/stevemccaskill/2019/03/25/tottenham-hotspur-stadium-uses-tech-to-offer-new-fan-experiences-and-faster-beer/#2f97e5065d38.

McLellan, S. (2019). *NBA experience debuts at Disney: Here's everything you need to know*. Good Morning America. https://www.goodmorningamerica.com/travel/story/nba-experience-debuts-disney-64863953.

Perez, M. (2019). *'Fortnite' world cup: By the numbers*. Forbes. Forbes Magazine. https://www.forbes.com/sites/mattperez/2019/07/26/fortnite-world-cup-by-the-numbers/#281ea5186be0.

Reed, A. (2020). *Manchester united to open three 'Experience Centers' in China by the end of 2020*. CNBC. https://www.cnbc.com/2019/01/08/manchester-united-to-open-three-experience-centers-in-china.html.

Smith, M. (2019). Game day reimagined: texas style. *Sports Business Journal*. https://www.sportsbusinessdaily.com/Journal/Issues/2019/08/19/In-Depth/Texas.aspx.

Soshnick, S., & Novy-Williams, E. (2019). *The NFL nears $25 billion revenue goal ahead of super bowl*. Chicago Tribune. https://www.chicagotribune.com/sports/ct-spt-nfl-revenue-super-bowl-20190128-story.html.

Symcox, J. (2019). *Cutting-edge app for Tottenham hotspur fans as stadium debuts*. BusinessCloud.co.uk. https://www.businesscloud.co.uk/news/cutting-edge-app-for-tottenham-hotspur-fans-as-stadium-debut.

USA Basketball—3 × 3 Rules of the Game. (n.d.). https://www.usab.com/3x3/3x3-rules-of-the-game.aspx.

Ben Shields Ph.D., is a Senior Lecturer in Managerial Communication at the MIT Sloan School of Management. He studies digital transformation in the sports, media, and entertainment industries. He is the co-author of *The Elusive Fan: Reinventing Sports in a Crowded Marketplace* and *The Sports Strategist: Developing Leaders for a High-Performance Industry*. Prior to MIT, he served as Director of Social Media at ESPN. He is an avid athlete, fan, and fantasy sports owner and fascinated by the role of technology in the live sports experience.

Irving Rein Ph.D., is a professor of Communication Studies in the School of Communication at Northwestern University. His research examines popular culture and how it influences our society. His recent co-authored books include *The Elusive Fan: Reinventing Sports in a Crowded Marketplace* and *The Sports Strategist: Developing Leaders for a High-Performance Industry*. As a fan and researcher, he is compelled by the live sports experience and how to improve it.

Virtual Reality and Sports: The Rise of Mixed, Augmented, Immersive, and Esports Experiences

Andy Miah, Alex Fenton, and Simon Chadwick

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

A. Miah (✉)
Science Communication & Future Media, University of Salford School of Science, Engineering and Environment, Manchester, UK
e-mail: A.Miah@salford.ac.uk

A. Fenton
Digital Business, University of Salford School of Business, Manchester, UK
e-mail: A.Fenton@salford.ac.uk

S. Chadwick
SKEMA Business School, Paris, France
e-mail: chadwick@em-lyon.com

277

and interesting. For example, in contact sports such as boxing or rugby—physically 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.

References

Balinger. (2019). *Zwift launches first e-racing league for pro riders featuring Cofidis, Team Wiggins and Canyon—SRAM*. Cycling Weekly. https://www.cyclingweekly.com/news/racing/zwift-launches-first-e-racing-league-pro-riders-featuring-cofidis-team-wiggins-canyon-sram-405569#jXz48cc7OUmM6UV2.99.

Beer, J. (2019). *I watched the NBA Playoffs in VR, and it's going to change how you watch sports.* Fast Company. https://www.fastcompany.com/90356626/i-watched-the-nba-playoffs-in-vr-and-its-going-to-change-how-you-watch-sports.

Biomajor & Oniatserj. (2017). *Dev: Summoning the worlds dragon transforming Beijing's bird's nest into a dragon's lair.* League of Legends. https://nexus.leagueoflegends.com/en-gb/2017/12/dev-summoning-the-worlds-dragon/.

Coca-Cola. (2015). *The Coca-Cola company joins forces with IGN for ESPORTS WEEKLY*. Coca-Cola. https://www.coca-cola.co.uk/stories/coke-joins-forces-with-ign-for-esports-weekly.

Craig, C. (2013). Understanding perception and action in sport: How can virtual reality technology help? *Sports Technology, 6*(4), 161–169.

Dredge. (2016). *Three really real questions about the future of virtual*. The Guardian. https://www.theguardian.com/technology/2016/jan/07/virtual-reality-future-oculus-rift-vr.

FC Bayern Munich. (2018). *FC Bayern App brings fan motifs to life*. https://fcbayern.com/en/news/2018/08/fc-bayern-app-brings-fan-motifs-to-life.

Gokeler, A., Bisschop, M., Myer, G. D., Benjaminse, A., Dijkstra, P. U., van Keeken, H. G., et al. (2016). Immersive virtual reality improves movement patterns in patients after ACL reconstruction: Implications for enhanced criteria-based return-to-sport rehabilitation. *Knee Surgery, Sports Traumatology, Arthroscopy, 24*(7), 2280–2286.

Gray, D. (2018). *FA deliver virtual advertising in England's World Cup warm up match*. Adi.tv. https://www.adi.tv/blog/2018/06/the-fa-deploy-adis-virtual-hybrid-digiboard-tech.

Hayward, A. (2019). *Populous director Brian Mirakian on designing the Esports Arenas of the future*. The Esports Observer. https://esportsobserver.com/populous-mirakian-hive-berlin/.

Hill, M. (2018). *AR dragon 'crashes' the stage at 'League of Legends' ceremony*. Newscast Studio. https://www.newscaststudio.com/2018/02/08/ar-dragon-league-of-legends/.

Holden, J. T., & Baker, T. A., III. (2019). The econtractor? Defining the Esports employment relationship. *American Business Law Journal, 56*(2), 391–440.

Hopper, N. (2018). *MLB teams up with AR technology to enhance the Ballpark experience*. Protolabs. https://www.protolabs.com/resources/blog/mlb-teams-up-with-ar-technology-to-enhance-the-ballpark-experience/.

Huffman, R. K., & Hubbard, M. (1996). A Motion based virtual reality training simulator for bob-sled drivers. In S. Haake (Ed.), *The engineering of sport* (pp. 195–203). Netherlands: Balkema Publishing.

Juul, J. (2005). *Half-real*. Boston: The MIT Press.

Landers, C. (2019). *Korea's SK Wyverns used augmented reality to bring a fire-breathing dragon to Opening Day*. Cut4 by MLB. https://www.mlb.com/cut4/korean-team-uses-dragons-on-opening-day.

Liverpool FC. (2018). *Reds fans to score at the Kop in world-first VR experience*. Liverpool FC. https://www.liverpoolfc.com/news/announcements/308852-reds-fans-to-score-at-the-kop-in-world-first-vr-experience.

Rettig, (2017). *STRIVR labs, DFB partner to make VR training work for Soccer Sport Techie*. https://www.sporttechie.com/strivr-and-german-football-association-dfb-form-vr-partnership.

Rosenberg, L. B. (1992). *The use of virtual fixtures as perceptual overlays to enhance operator performance in remote environments*. Technical report AL-TR-0089, USAF Armstrong Laboratory, Wright-Patterson AFB OH.

Sony Entertainment Interactive, LLC (2019). *Scaled VR engagement and views in an E-sports event*. World Intellectual Property Organization. https://patentimages.storage.googleapis.com/46/01/3d/c1a2469985d593/WO2019168637A1.pdf.

The Morning Show. (2019). *Esports could be heading to the Olympics, says IOC President Thomas Bach*. 7 Network. https://7news.com.au/the-morning-show/esports-could-be-heading-to-the-olympics-says-ioc-president-thomas-bach-c-95961.

Torres, J. C. (2016). *VR will be the most "anti-social" social, platform*. Slash Gear. https://www.slashgear.com/vr-will-be-the-most-anti-social-social-platform-02429959/.

Vignais, N., Kulpa, R., Brault, S., Presse, D., & Bideau, B. (2015). Which technology to investigate visual perception in sport: Video vs. virtual reality. *Human Movement Science, 39*, 12–26.

Whiteman-Stone, D. (2019). *Asos launches its first augmented reality feature*. Fashion United. https://fashionunited.uk/news/retail/asos-launches-its-first-augmented-reality-feature/2019061443676.

Andy Miah Ph.D., is Chair of Science Communication & Future Media in the School of Science, Engineering and Environment at the University of Salford, Manchester. His research focuses on the promise and peril of new technologies and his career has spanned such areas as genetics, nanotechnology, and transhumanism. He is a keen runner and sometimes triathlete, happiest when off the beaten track. His interest in this book is born out of a desire to understand what happens to humanity in a world where digital and biotechnological innovations rapidly transform how we live and how we evolve.

Alex Fenton Ph.D., is Associate Dean International at the University of Chester in the UK. His research is focused on how innovative digital technologies can improve business processes and impact positively on individuals. Prior to becoming an academic, he ran a digital development company and helped to get Manchester online with the Virtual Chamber in 1997. He also created a smartphone project for major sports clubs called Fan Fit, which helps fans to get active as an official club app. In his free time, he can be found making real cider and organizing festivals of music or technology. His section, focused on virtual reality and fans, was inspired by his love of sport and digital technologies and associated research with sports clubs and their supporters.

Simon Chadwick Ph.D., is Professor of Sport and Geopolitical Economy at Skema Business School in Paris. His research is positioned at the intersection of sport, business, digital, and politics. Chadwick has worked for some of the world's leading business schools, as well as for some of the most important and influential organizations in the world of sport. Once a regular athlete and sports participant, he constantly seeks to make sense of a complex world through the lens of sport. Nowadays, he walks a lot whilst thinking about sport.

How Technologies Might Change the European Football Spectators' Role in the Digital Age

Dominik Schreyer

Abstract

Spectators play a vital role in professional sports. As such, it may not surprise that many football clubs continue to pursue stadium expansion and increase seat supply. Still, as new technologies like artificial intelligence, augmented reality, and blockchain technology enter the mass market, the question arises if the strategy of ever-increasing the seat supply will ultimately be sustainable. Accordingly, in this short chapter, I attempt to predict how such technologies might change the European football spectators' role in the digital age, specifically focusing on the potential role of augmented and virtual reality in shaping stadium attendance demand in 2040. In total, I make ten projections, cumulatively pointing to the European football spectators' loss of significance.

1   The European Football Spectators' Role

Spectators play a vital role in professional sports. For instance, for many European football clubs, spectators are a natural and, more importantly, significant source of income, directly through match day income, not least from ticket sales, and indirectly, as they create stadium atmosphere, which can be monetized through commercial partners looking for an emotional stage to differentiate their products or services. Often coined a team's 12th (wo)man, spectators are also known to contribute to home advantage (e.g., Reade et al., 2022). By applauding, booing, cheering, dancing, and singing, they affect the experience of both spectators on site (e.g., Stieler et al., 2014), including those sitting in high-margin business

D. Schreyer (✉)

Center for Sports and Management (CSM), WHU—Otto Beisheim School of Management, Dusseldorf, Germany
e-mail: dominik.schreyer@whu.edu

seats or executive suites, and those watching from afar (e.g., Behrens & Uhrich, 2022). Intriguingly, for those football clubs increasingly looking to diversify their income sources (c.f., Schmidt & Holzmayer, 2018), a crowded stadium might also help generate supplemental income in advance of matchday, with spectators arriving earlier to attend a guided stadium tour, visit the club's museum, or indulge in other club-related activities (e.g., escape rooms, karting, or skywalks). Accordingly, financial investors equate a football club's reputation with the stadium attendance demand (Gimet & Montchaud, 2016). Intriguingly, traditional models of sports consumption behavior consider habitual stadium admissions a natural end point of the consumption spectrum. Media consumption, in contrast, is a mere antecedent of such habitual stadium visits (e.g., Mullin et al., 2014).

Against this background, it may not surprise that many football clubs continue to pursue stadium expansion and increase seat supply. For example, in the English Premier League, where most clubs own their stadium (UEFA, 2023), Manchester City has announced plans to expand Etihad Stadium's capacity to more than 60,000 seats—by roughly 7,700 seats, or almost 15%—and add a club shop and a museum, among others, in an attempt to turn the city council-owned campus into a year-round entertainment and leisure destination (e.g., Forbes, 2023). In the Spanish La Liga, both Futbol Club Barcelona and Real Madrid Club de Fútbol have similar strategies (ESPN, 2021). Other notable stadium (expansion) plans in European professional football include Everton's new Everton Stadium at Bramley-Moore Dock (e.g., Forbes, 2020a), Karlsruhe's BBBank Wildpark (e.g., Focus, 2018), and Liverpool's Anfield (e.g., Forbes, 2020b) with additions of about 13,000, 4,000, and 16,000 seats, respectively.

Still, as new technologies like artificial intelligence (AI), augmented reality (AR), and blockchain technology enter the mass market, the question arises if the strategy of ever-increasing the seat supply will ultimately be sustainable. Will these stadiums (still) be crowded in the near future, say 2040? Or will we enter a decade of mostly empty stadium seats as early as 2030? Could this be the decade in which these stadiums finally lose their birthright as an essential part of the sporting product offered to (television) audiences? If so, how will this then affect the European football spectators' often still impactful position in the football business?

Accordingly, in this short chapter, I attempt to predict how such technologies might change the European football spectators' role in the digital age. Although I am fully aware that predicting the future is, by its nature, a challenging task, I hope to initiate a discussion on whether we, as a society, still need football stadiums in the future and, if so, what will the spectators' role be therein.[1] Specifically, I will focus on the potential role of AR and virtual reality (VR) in shaping the stadium experience in 2040, both of which are also discussed, to some degree, elsewhere in this book (Miah et al., 2020; Shields & Rein, 2020) as well as on AI

---

[1] Throughout this chapter, I differentiate between spectators, i.e., those physically attending a stadium to watch a football match live, and audiences, i.e., those watching a football match live on any screen. For recent reviews scoping the literature, I refer to Schreyer and Ansari (2022) and van Reeth (2023), respectively.

(e.g., Torgler, 2020). In so doing, I expand on previous thoughts (c.f., Schreyer & Behrens, 2023) that explore technology's effect on the European football spectators' most prominent current roles, i.e., as a natural source of income and as a source of home advantage. However, I also touch upon closely related questions and other technologies while mostly, though not entirely, ignoring other potential megatrends, including the imminent demographic shifts.

2 How Technologies Might Change the European Football Spectators' Role

In this section, I sketch how technologies might change the European football spectators' role in the digital age. More specifically, once I have established some preliminary thoughts indicating that—without any significant changes—stadium attendance demand for European football will likely decline, I first discuss whether VR and AR are set to amplify or weaken such a scenario. In particular, I am keen to explore whether such applications will limit the European football spectators' role as a source of income directly (e.g., matchday income) and indirectly (e.g., commercial income, including sponsorship). Afterward, I will turn my attention to AI and discuss its potential to end the European football spectators' role in creating home advantage. Finally, I also touch upon the possibility of two alternative technologies—blockchain and holographic technology—that could pave exciting alternative paths.

2.1 In the Future, Stadium Attendance Demand for European Football Will Likely Decline

Projection 01:In 2040, stadium attendance demand for European football will have decreased significantly

Once the primary barrier to cross, the football stadium's gates have long lost their function as an exclusive paywall and restrictor of access. Consequently, as is evident from a look at the so-called Deloitte Football Money League, i.e., the 20 European football clubs with the highest turnover in a respective year, the relative importance of matchday income has significantly decreased. That is, while such income accounted for roughly 28% of a club's total yearly income (excl. transfers) in 2005–06, the relative share successively declined to about 15% before the pandemic (Deloitte, 2020). Similarly, in Germany's Bundesliga, typically the most in-demand European football league (DFL, 2020), football clubs have generated about 16% of their total income through this income stream. For comparison, in the last complete season before the pandemic, the relative share of media income for these 18 clubs was about 44% (DFL, 2020).

While European football stadium attendance demand still seems relatively stable at first sight, both anecdotal and empirical evidence exists that this

demand—captured by the number of disseminated tickets—is significantly lower than usually accepted and declining. More specifically, in Bundesliga, for instance, clubs distributed, on average, 40,483 tickets per match in the last five seasons before the pandemic. However, a fair share of these tickets, about 57%, were distributed to season ticket holders, who do not attend all matches during a season (e.g., Karg et al., 2019). Often neglected, the resulting season ticket no-show behavior, in terms of numbers, can be significant; some European football clubs face season ticket holder no-show rates in the double-digit percentages (e.g., Schreyer et al., 2016). However, no-show behavior also extends to more casual matchday ticket holders (e.g., Schreyer & Torgler, 2021) and across different sporting environments, including Australian Rules Football (e.g., Karg et al., 2021) and college football (e.g., Popp et al., 2023), where three in 10 distributed tickets remained unused in the season 2017. Consequently, in Bundesliga, no-show behavior resulted in an effective stadium utilization of only about 80% in the season 2017–18, down from roughly 83% in the season 2014–15 (c.f., Schreyer, 2019).

If this trend is characteristic of the European football market, then the effective demand for such football matches is already in decline. Given that the pandemic may have altered spectator perspectives (e.g., Wilkesmann, 2022), there is little to suggest a turnaround any time soon. Quite the contrary, there is, however, much to suggest that stadium attendance demand for European football will further decline in the future, including aging season ticket holders (e.g., Schreyer & Torgler, 2021), increasingly inconvenient scheduling decisions (e.g., early/late kick-off times, mid-week matches), and an increasing number of competitors vying attention (e.g., Netflix, Peloton, and TikTok, to mention just a few), some of which are keen to change the people's game drastically (e.g., Kings League; c.f., New York Times, 2023).

2.2 Advances in AR/VR Applications Might Limit the European Football Spectators' Role as a Natural Source of Income

2.2.1 VR Technology Will Amplify the Imminent Decline in Stadium Attendance Demand
VR Experiences Will Emerge as a Natural and Potent Substitute

> Projection 02:In 2040, most European football fans will consider VR stadium experiences a perfect substitute for physical stadium experiences

While our understanding of VR applications as a potential substitute for the stadium experience is limited at best, it seems likely that the rise of such applications will play a major role in the decline in stadium attendance demand (e.g., Schmidt et al., 2023). As VR technology matures, current physiological adoption barriers (e.g., headaches; c.f., Frevel et al., 2022) may resolve entirely, offering football audiences a spectator-like experience without missing out on crucial

information (e.g., commentary, live statistics, replays, and video assistant referee (VAR) decisions) and, more importantly, exhausting travel (e.g., Schreyer et al., 2018). Put differently, while still a niche rather than a mass market phenomenon, such VR applications may soon be able to combine the best of two worlds—the stadium experience and a TV broadcast—in an immersive and highly individualized social experience. Eventually, this experience could allow audiences to opt for their preferred catering options and pause for a quick run to the bathroom whenever necessary. Often overlooked, such a digital environment might attract a more female audience, a group still underrepresented in most European football stadiums, to the (virtual) stands (e.g., Schreyer & Torgler, 2021). It is, therefore, certainly no surprise that some sports associations and federations, most notably the Women's National Basketball Association (WNBA) and the National Basketball Association (NBA), have begun exploring the potential to distribute some of their games in immersive 180-degree VR in the US market (SportsPro, 2023). Meanwhile, in European football, Manchester City is exploring the concept of a virtual Etihad Stadium in a project with Sony (The Verge, 2023). However, whether the club will rely on immersive VR technology remains unclear. Other football clubs, including VfL Wolfsburg (2023), have tested similar virtual stadium environments in Web 3.0.

As VR Technology Hits the Mass Market, European Football Executives Will Rethink Their Pricing Strategy

> Projection 03:In 2040, European football spectators in the public area of a stadium no longer pay an entrance fee

As VR technology hits the mass market, European football executives have different options to tackle the imminent decline in stadium attendance demand, including reducing the existing stadium capacity. However, as revamping the stadium—or even building it all again from scratch—takes significant financial investments, among others, some football executives facing an oversupply of (empty) seats might even opt for more radical changes in their business model. For instance, as those spectators in the public area of a stadium, in particular, are an essential input to selling high-margin premium packages, the management might opt to distribute many, or even most, tickets for public sections of the stadium for free or at a heavy discount; in so doing, they give up one business to keep the more profitable (hospitality) business up and running. In fact, given that most European football clubs generate about 62% of their matchday income by selling only about 10% of their seats (ESSMA, 2019), i.e., those seats in the executive or hospitality sections of the stadium, such a move might be beneficial regardless. Intriguingly, recently, a German professional football club—Fortuna Düsseldorf—announced an initial attempt to offer domestic league matches for free in the future (e.g., Spiegel, 2023). Somewhat similarly, though less radical, fan-owned Spanish football clubs Unionistas de Salamanca and SD Logroñes have recently begun

exploring the potential of offering interested fans stadium access through partici-pative pricing mechanisms (e.g., pay what you want; c.f., Sánchez, 2022). Other football clubs, mostly in lower leagues, though, have allowed season ticket hold-ers to occasionally bring a friend for free (e.g., Waldhof Mannheim, 2022) or, like Cadiz CF, rewarded their most behaviorally loyal season ticket holders with free season tickets (e.g., Marca, 2022).

2.2.2   AR Technology Might Slow Down Rather Than Stop or Convert the Imminent Decline in Stadium Attendance Demand

AR Will Help Reduce Existing Information Gaps Between Audiences and Spectators

> Projection 04:In 2040, AR technology can eradicate information asymmetries in the stands

AR technology, i.e., technology that allows the integration of digital objects in the physical world, is at the heart of a common argument against declining stadium attendance demand. More specifically, while potentially superior virtual experi-ences that deliver on olfactory, tactile, and perhaps even gustatory senses are not yet ready for the market, AR applications might help bridge the current informa-tion gap between TV audiences and spectators. In short, such applications might add specific layers, most notably live data, to the stadium experience, providing spectators with otherwise unavailable information. Both associations (e.g., FIFA) and leagues (e.g., Bundesliga) have long begun exploring such services, offer-ing spectators real-time statistics (e.g., heatmaps) and (VAR) replays, even from different camera angles, through smartphones (Engadget, 2022).

Ultimately, AR Technology Will Expand the Digital Divide

> Projection 05:In 2040, most European football spectators object to AR technology in the stands

Even though there's no immediacy to fear that European football spectators will no longer follow a match once their smartphone runs effectively on-side (e.g., Naraine et al., 2020), many spectators may initially object to or even resist access-ing AR applications on the ground—not least because the technology might distract spectators from the live experience, interferes with established rituals, and, more generally, reduces social interactions among fans. Still, technological advancements may mitigate some of these adoption barriers (Uhlendorf & Uhrich, 2022). For instance, rather than requiring smartphones, in the future, these appli-cations may run on glasses or even contact lenses, which are likely to enter the market within the next few years (e.g., Road to VR, 2022). However, unlike smart-phone users, spectators wearing smart glasses, lenses, or—in the near future—even implants with AR applications can easily record (and capture) images and videos without another spectator's knowledge or consent, which raises significant con-cerns about privacy violations and potential data misuse, specifically as AI evolves.

Further, with such a wearable constantly in use, potentially distracted spectators may not be fully present in social situations and, therefore, miss out on critical social cues essential to generate the stadium atmosphere.

Keeping high investment costs and regulatory questions aside for the moment, exploiting AR applications may, therefore, ultimately split the stadium crowd into two large and distinct groups. In one group are the purist traditionalists who object to digital stadium experiences (e.g., AR applications, blockchain-based/digital ticketing) but remain keen to support their team on the pitch and, thus, generate the stadium atmosphere. In the other group are the tech-savvy fans, most of whom enjoy rather than create this atmosphere. However, with enough potential substitutes for this second group already on the horizon (e.g., Holography, VR applications), it seems likely that many of them will leave the stadium experience behind for good, effectively (further) reducing the heterogeneity in the stands.[2]

Importantly, objection to AR technologies does not necessarily mean that stadiums remain stagnant technologically; quite the contrary, it is likely that they will undergo significant changes as technology advances. Despite some European football clubs' recent initiatives to attract younger spectators, most notably by introducing relatively cheap tickets for these fans (e.g., Manchester United, 2018), the stadium crowd is aging (c.f., Schreyer & Torgler, 2021).[3] As such, somewhat counterintuitive at first, digitalizing a European football stadium might refer to significant financial investments in Internet of Things (IoT) solutions enabling elevators, escalators, and moving walkways to move the aging crowd efficiently and safely through the stadium rather than to 5G or AR initiatives.

2.2.3 AR/VR Might End the European Spectators' Role as an Input of the Media Product
As Technology Progresses, Spectator-Independent Media Production Will Become Likely

Projection 06:In 2040, European football spectators will take no part in media production

With VR applications emerging as a potentially powerful substitute for both broadcasts and the stadium experience, a natural and related question is whether media production will continue to rely on spectators to excel (e.g., Behrens & Uhrich, 2022). Looking back at the pandemic, I believe that the opposite is true. More precisely, when football was played behind closed doors, there was already an

---

[2] Increasing digital fatigue would result in a similar scenario, though not necessarily introducing a digital divide. In such an alternative scenario, technology enabling the use of AR could even be banned from the stands.

[3] Somewhat ironically, those sports fans most likely to enjoy AR technology in the stands seem to have no specific interest in watching sports live in a stadium in the first place. For instance, according to market research, about every second member of the so-called Generation Z in the US market, a staggering 47% had never watched a professional sporting event live in person (Morning Consult, 2022), with one in three not even watching live sports at all.

initiative to digitally replace spectators during production (e.g., Reuters, 2020). In the US sports broadcasts, in particular, they continue to experiment with real-time 3D animation of players and their surroundings (e.g., NFL, 2020; NHL, 2023) and even avatars (e.g., NBA, 2023). Consequently, as technology progresses, spectators during production might become obsolete; and football matches might be produced as if in front of a green screen, with an augmented emotional crowd, potentially still necessary to cater to third-party needs. Importantly, even though controversial, such a strategy would also cater to the various needs of commercial sponsors, all of which seek a crowded, emotional stage—rather than a mostly empty stadium—to differentiate their products or services.

Cut off from Media Production, Spectators' Stadium Behavior Will Change

> Projection 07:In 2040, European football spectators create a more hostile stadium atmosphere

While spectator-independent media production certainly has its merits, most notably a more manageable media product, it will also come with a price. For example, the crowd will be denied a platform that spectators have historically used to draw attention to existing (political or social) problems, thus eliminating yet another argument to enter the stands in the first place. Even worse, as racial abuse still exists in some European football leagues (e.g., Caselli et al., 2023), even with an audience watching, it seems likely that such tendencies will continue or even increase when operating behind a curtain. Put differently, with those mostly passive and moderate spectators leaving the stands, highly identified spectators remaining might opt to create a more hostile atmosphere, targeting the visiting team, or even individual players, to increase home advantage.

2.3   AI Will Reduce the European Football Spectators' Role in Creating a Home Advantage

> Projection 08:In 2040, European football spectators do not contribute to home advantage

While a more hostile stadium atmosphere could increase home advantage in the future, I expect that advancements in AI will neutralize such potential gains. In fact, considering what we have learned about the effects of absent spectators on (football) player performances and refereeing decisions during the pandemic (e.g., Endrich & Gesche, 2020), another decline in home advantage seems almost inevitable; it is also reflective of the demise of home advantage evident in European football and beyond (e.g., Peeters & van Ours, 2021; Reade, 2019; Singleton et al., 2021). More precisely, while banning spectators from the stands did affect home advantage during the recent pandemic, the relatively small effect sizes reported in this natural experiment (e.g., Bryson et al., 2021) indicate that partisan crowds

barely affect football match outcomes even today. Against the background of technological advancements in AI, many of which are likely to enhance or replace VAR and even the referee eventually, it is unlikely that crowds will continue influencing decisions on the pitch. For instance, during the 2022 World Cup Qatar, FIFA introduced a new system, the so-called semi-automated offside technology, which used AI, among others, to detect offside situations more efficiently.

2.4   Other Technologies Could Pave Exciting Alternative Paths

2.4.1 Holographic Technologies Could Revive Empty Stadiums

Projection 09:In 2040, few European football spectators will enjoy holographic technology

Even though I'm primarily interested in sketching out how AI, AR, and VR technology might affect the European football spectators' role in the digital age, other technologies might moderate whether my predictions hold in the future. For instance, a related and exciting question is whether spectators might enjoy football matches delivered through holograms or robotics, perhaps even to relive historical football matches collectively. While the latter scenario seems unlikely, not least given the critical but ambiguous role of suspense and surprise in professional sports (e.g., Schreyer et al., 2016), a niche might emerge for such alternative experiences nevertheless. In 2022, Swedish pop band ABBA staged their first concert in 42 years in hologram form at London's Queen Elizabeth Olympic Park (The Guardian, 2022); as the technology progresses, similar experiences might attract some interest, particularly for unique, once-in-a-lifetime football experiences (e.g., a European Championship or a World Cup final) that are likely to generate more demand than seats even as overall demand declines. Alternatively, despite the potential objections outlined above, the technique might add an exciting entertainment layer to pre-/post-match or halftime shows in the stadium. Offering such an alternative experience might modestly recalibrate the European football spectators' role as a natural source of income, but—given that tech-savvy football fans might opt for alternative distribution channels—the decrease in crowd-induced home advantage will likely remain.

2.4.2 Blockchain Technology Could Alter the Stadium Experience

Projection 10:In 2040, European football spectators do not participate in sporting decision-making

While I expect stadium attendance demand for European football to decrease eventually, blockchain technology might offer an opportunity for an exciting turnaround, despite the extant controversies (e.g., considering personalized tickets). More precisely, using the technology, spectators could, for instance, influence game-specific decisions through digital voting in the stands (e.g., on line-ups,

penalty takers, and substitutions). Examples already exist in other sports, like Fan Controlled Football (e.g., Schmidt & Flegr, 2023) or in Gerard Piqué's Kings League (New York Times, 2023). Naturally, a similar mechanism would massively affect the game, making such spectator participation rather unlikely—at least in European professional football. Further, and more importantly, with most football fans being devoted audiences rather than spectators, the question becomes why associations and leagues should give preference to spectator needs in the first place.

3   A Possible Scenario: European Football Spectators' Loss of Significance

Synthesizing these ten initial projections, a scenario emerges in which technology has significantly changed the European football spectators' role in 2040. More specifically, I envision a future where spectators—unlike audiences—play a subordinate role for European football clubs and their external stakeholders.

Against the background of a naturally occurring decline in stadium attendance demand for European football in the future (c.f., projection #01), I expect both AR and VR to amplify rather than mitigate or even reverse the European football spectators' already diminishing role as a natural source of income. More specifically, as VR applications emerge as potent substitutes for the physical stadium experience, most, though not all, European football fans will likely consider moving to a virtual environment (#02), further reducing stadium attendance demand. Similarly, AR technology, often considered a means to close the evident information asymmetries between audiences and spectators (#04), as well as to enhance the stadium experience, could ultimately expand the existing digital divide, with traditionalists turning their backs on such applications and tech-savvy spectators converting to members of the VR audience (#05) where they can enjoy an increasingly personalized even stadium-like football experience (e.g., Schmidt et al., 2023). While the resulting decrease in stadium attendance demand might prompt executives to lower ticket prices, perhaps even allowing the public to enter the stands free of charge (#03), matchday income is doomed to decline significantly nevertheless. Intriguingly, as spectator interest generally declines, a spectator-independent production process becomes increasingly likely (#06), further lowering the incentives to visit the stadium, even for traditionalists who might mostly object to some tech-supported alternatives (#09) and be excluded from others (#10).

Importantly, this does not necessarily mean that there will be no stadiums in the future or that technology will not play a part in shaping the spectator experience. For instance, while outside my scope of this chapter, it looks likely that AI and robotics, in particular, will play a significant role in more efficiently running

matchday operations by 2040.[4] However, as indicated earlier, it seems even more likely future technological investment will cater to the varying accessibility needs of the aging spectator group rather than enable AR applications through 5G (or a follow-up technology). Effectively, with tech-savvy fans crowded out of the stadium and technology taking a back seat, remaining stadium enthusiasts—cut off the screen—are, therefore, likely to enjoy a relatively archaic matchday experience and create a more hostile stadium atmosphere (#07) without contributing to home advantage (#08).

Naturally, an investigation of whether and how technologies might change the European football spectators' role in the digital age does not end here. Many related questions remain; for instance, regarding spectators' impact on third parties, not least the environment. In this regard, an interesting question would be whether lower stadium attendance demand, a spectator-independent production process, and a potentially more hostile atmosphere may prompt executives to (1) increase demarketing initiatives, thereby making the stadium an effectively ad-free environment; (2) turn to multipurpose arenas; or (3) opt to systematically supply fewer seats, for instance, by dismantling existing and rebuilding significantly smaller stadiums.

In particular, exploring whether to reduce the seat supply seems crucial for European football clubs, specifically due to a stadium's relatively long lifecycle.[5] More specifically, because empty seats breed empty seats (e.g., Oh et al., 2017), eliminating such empty seats by reducing oversupply could help slow down the otherwise imminent move toward a (mainly) spectator-independent production. Creating demand that exceeds supply is also essential to maintain some price-setting power for the time being. Consequently, it's unsurprising that some NFL teams have opted for smaller stadiums recently (c.f., Field of Schemes, 2022).

On a more general note, a decrease in available seats might also help European football clubs reduce their often significant environmental footprint, irrespective of whether demand—currently or in the future—meets supply. As Loewen and Wicker (2021) estimate, a spectator's carbon footprint is about 311 kg of carbon dioxide equivalent emissions, on average, from traveling to Bundesliga home matches alone. As such, supplying fewer seats, among others (e.g., technological advances), would not only help reduce football-induced emissions but also save energy and water and reduce waste.

Alternatively, in an extreme manifestation of this scenario, the imminent decline in stadium attendance demand might even offer a possible path for a continuous

---

[4] For instance, AI-assisted facial recognition technology could help replace physical (or even digital) tickets, thus eliminating problems in crowd management due to ticket scans (e.g., Wired, 2023) and reducing safety threats; that is, even though such a scenario seems unlikely if spectators object for privacy reasons. Similarly, some stadiums have begun integrating Amazon's Just Walk Out technology, resulting in a faster, frictionless shopping experience for interested stadium visitors (e.g., AFL, 2023; MLB, 2022; Seattle Seahawks, 2022).

[5] As technology advances, future stadiums could be characterized by increased modularity, with the host in-/decreasing the capacity at the push of a bottom if necessary.

but temporary re-location of the few teams that can still generate enough stadium attendance demand. Put differently, with most football matches produced independently of spectators in the future, some football teams could become 'homeless' to attract international spectators to profitable, high-margin stadium experiences. Given that some leagues, including La Liga (Reuters, 2022) and the National Football League (NFL, 2022), already host a fraction of their domestic competitions abroad, such a scenario seems relatively likely. Suppose top teams rotate through global stadiums as overall demand declines. In that case, it feels inevitable that new stadium projects, if greenlit, will need to be multipurpose stadiums generating football-unrelated income (e.g., through the operation or rental of bars and restaurants, (club) museums, fitness centers or office space, and even supermarkets) year-round, effectively replacing monofunctional football arenas.

Finally, a natural question is whether the aforementioned technological advancements might affect European women's football differently than men's. While I believe similar mechanisms hold in the two markets, if anything, I think it is even more likely that European football spectators are neglectable from a business perspective, despite the more recent hype and the occasional stadium attendance records. However, the women's market has not reached the stadium attendance demand of the men's; they are in different places economically. More precisely, with a cumulated matchday income of about 12 million euros (e.g., UEFA, 2022),[6] European women's football is largely spectator-independent already. Accordingly, executives might decide to invest in technological solutions that cater to the specific needs of their most important stakeholder group—audiences—rather than slowly growing attendances.

4   Conclusion

While I have sketched out a scenario ultimately projecting the European football spectators' loss of significance, it is important to stress that this is one possible scenario among many. Effectively, multiple futures exist, many of which might reject certain aspects of the scenario I predicted above. Some might even prove my ideas and assumptions wrong entirely. Even though I am convinced that stadium attendance demand is likely to decline by 2040, not least due to the vast amount of potential substitutes, including, but not limited to, VR applications, I believe that there exists a market for such experiences in the physical world, despite the increasing need for more immersive and highly personalized digital experiences (c.f., Schmidt et al., 2023). As such, it seems reasonable that the European football spectators' social role, attracting a more local community, might ultimately remain

---

[6] To paint a complete picture, UEFA (2022) expects matchday income to increase ninefold by 2033, thus growing stronger relative to sponsorship and media income. However, even if this base case realizes, European women's football would still generate less matchday income than what Arsenal London generated before the pandemic. For comparison, in Women's Bundesliga, clubs generate less than 10% of their income through gate receipts.

in the future, despite the loss of significance mentioned earlier. Only time will tell how large this market will be and, considering a potential digital oversaturation, whether European football spectators will continue to play an essential role in the digital age. Nevertheless, I hope these initial thoughts, which I hope to extend and reflect on again in the near future, will inspire a debate on the future role of spectators and stadiums and help football executives prepare their clubs for a potentially radically different future.

References

Australian Football League [AFL] (2023, April 3). *AFL and Amazon to introduce Just Walk Out technology at Marvel Stadium.* https://tinyurl.com/nhby3jcb

Behrens, A., & Uhrich, S. (2022). You'll never want to watch alone: The effect of displaying in-stadium social atmospherics on media consumers' responses to new sport leagues across different types of media. *European Sport Management Quarterly, 22*(1), 120–138.

Bryson, A., Dolton, P., Reade, J. J., Schreyer, D., & Singleton, C. (2021). Causal effects of an absent crowd on performances and refereeing decisions during Covid-19. *Economic Letters, 198*, 109664.

Caselli, M., Falco, P., & Mattera, G. (2023). When the stadium goes silent: How crowds affect the performance of discriminated groups. *Journal of Labor Economics, 41*(2), 431–451.

Deloitte. (2020). *Football Money League.* Manchester: Deloitte.

Deutsche Fußball Liga [DFL] (2020). *Economic Report*.

Endrich, M., & Gesche, T. (2020). Home-bias in referee decisions: Evidence from "Ghost Matches" during the Covid19-Pandemic. *Economics Letters, 197*, 109621.

Engadget (2022, December 2). *World Cup attendees can use AR to see stats for players on the pitch.* https://tinyurl.com/5dtnd4hx

ESPN (2021, October 20). *Barcelona reveal plans for Camp Nou redevelopment to rival Real Madrid's Bernabeu.* Accessed March, 21, 2023. https://tinyurl.com/2p92vu6z

European Stadium & Safety Management Association [ESSMA] (2019). *Hospitality Benchmark*.

Field of Schemes (2022, November 23). *Here's why NFL teams want smaller stadiums, and it's not about saving fans from nosebleeds.* https://tinyurl.com/mu87bwad

Focus (2018, September 26). Neues Stadion im Wildpark [New stadium at Wildpark]. https://tinyurl.com/hm3vdk6w

Forbes (2020a, February, 20). *Everton's New Stadium Capacity And Timeline Revealed Ahead Of Planning Consultation.* https://tinyurl.com/a2bzj5em

Forbes (2020b, February 13). *Liverpool Plan 61000-Capacity Anfield With NFL And Gaelic Games Option.* https://tinyurl.com/32b8ktpu

Forbes (2023, March 10). *Manchester City Plans For Etihad Stadium Expansion Include A Workforce Of The Future.* https://tinyurl.com/4k8amj8rForbes (2020, February 20). *Everton's New Stadium Capacity And Timeline Revealed Ahead Of Planning Consultation.* https://tinyurl.com/bddc8un4

Frevel, N., Beiderbeck, D., & Schmidt, S. L. (2022). The impact of technology on sports–A prospective study. *Technological Forecasting and Social Change, 182*, 121838.

Gimet, C., & Montchaud, S. (2016). What drives european football clubs' stock returns and volatility? *International Journal of the Economics of Business, 23*(3), 351–390.

Karg, A., McDonald, H., & Leckie, C. (2019). Channel preferences among sport consumers: Profiling media-dominant consumers. *Journal of Sport Management, 33*(4), 303–316.

Karg, A., Nguyen, J., & McDonald, H. (2021). Understanding season ticket holder attendance decisions. *Journal of Sport Management, 35*(3), 239–253.

Loewen, C., & Wicker, P. (2021). Travelling to Bundesliga matches: The carbon footprint of football fans. *Journal of Sport & Tourism, 25*(3), 253–272.

Manchester United (2018, April 03). United confirm 2018/19 ticket prices. https://tinyurl.com/zuy4bxbw

Marca (2022, July 13). *Más de 10.000 abonados verán al Cádiz en Primera... ¡gratis!* https://tinyurl.com/j6tzb8r5

Miah, A., Fenton, A., & Chadwick, S. (2020). Virtual reality and sports: The rise of mixed, augmented, immersive, and esports experiences. *21st century sports: How technologies will change sports in the digital age*, 249–262.

Major League Baseball [MLB] (2022, April 27). *New "Walk-Off Market" eliminates checkout lines and gives fans the option to enter and pay with just their palm.* https://tinyurl.com/yckzrrzb

Mullin, B. J., Hardy, S., & Sutton, W. (2014). *Sport marketing* (4th edition). Human Kinetics.

Naraine, M. L., O'Reilly, N., Levallet, N., & Wanless, L. (2020). If you build it, will they log on? Wi-Fi usage and behavior while attending National Basketball Association games. *Sport, Business and Management: An International Journal.* https://doi.org/10.1108/SBM-02-2019-0016

National Basketball Association [NBA] (2023, February 17). *Adam Silver unveils streaming experience of the future via the NBA App at 2023 NBA All-Star Tech Summit.* https://tinyurl.com/yeyw5w55

New York Times (2023, April 5). *Gerard Piqué's Kings League Has Seen Soccer's Future.* https://tinyurl.com/56vvt3e8

National Football League [NFL] (2020, December 15). *CBS Sports, Nickelodeon team up to air 'NFL Wild Card Game on Nickelodeon' on Jan. 10.* https://tinyurl.com/5n6cv4t7

National Football League [NFL] (2022, May 22). *NFL announces five games for 2022 International Series.* https://tinyurl.com/pazdfhu7

National Hockey League [NHL] (2023, March 13). '*NHL Big City Greens Classic' adds new dimension to Rangers-Capitals game.* https://tinyurl.com/28ft7nt9

Oh, T., Sung, H., & Kwon, K. D. (2017). Effect of the stadium occupancy rate on perceived game quality and visit intention. *International Journal of Sports Marketing and Sponsorship, 18*(2), 166–179.

Peeters, T., & van Ours, J. C. (2021). Seasonal home advantage in English professional football; 1974–2018. *De Economist, 169*(1), 107–126.

Popp, N., Simmons, J., Shapiro, S. L., & Watanabe, N. (2023). Predicting ticket holder no-shows: Examining differences between reported and actual attendance at college football games. *Sport Marketing Quarterly, 32*(1), 3–17.

Reade, J. J. (2019). Officials and Home Advantage. *The SAGE Handbook of Sports Economics.*

Reade, J. J., Schreyer, D., & Singleton, C. (2022). Eliminating supportive crowds reduces referee bias. *Economic Inquiry, 60*(3), 1416–1436.

Reuters (2020, June 7). *La Liga to use 'virtual' stands and audio for broadcasts.* https://tinyurl.com/techspec01.

Reuters (2022, January 11). *Saudi Spanish Super Cup sparks debate as fans 'forgotten'.* https://tinyurl.com/4cpa6d5f

Road to VR (2022, July 5). *Hands-on: Mojo Vision's Smart Contact Lens is Further Along Than You Might Think.* https://tinyurl.com/4wh9n8sy

Sánchez, L. C. (2022, May 26). *Price What You Want in football: the case of fan owned clubs "Unionistas de Salamanca" and "SD Logroñes"* [Paper presentation]. 8th Western Conference on Football and Finance. https://tinyurl.com/48525bcf

Schmidt S. L., & Holzmayer F. (2018). A framework for diversification decisions in professional football. *Routledge Handbook of Football Business and Management*, 3–19.

Schmidt, S. L., & Flegr, S. (2023). Lessons on Customer Engagement from Fan Controlled Football. *Harvard Business Review Online.* https://tinyurl.com/3rwd7ksp

Schmidt, S. L., Geissler, D., & Schreyer, D. (2023). *Top-tier sports product and its production in 2030.* Center for Sports and Management (CSM), Düsseldorf/Vallendar: WHU.

Schreyer, D. & Behrens, A. (2023). Die Rolle des Stadionpublikums im globalisierten Teamsport. *Entwicklungstendenzen im Sportmanagement.*

Schreyer, D. (2019). Football spectator no-show behaviour in the German Bundesliga. *Applied Economics, 51*(45), 4882–4901.

Schreyer, D., & Ansari, P. (2022). Stadium attendance demand research: A scoping review. *Journal of Sports Economics, 23*(6), 749–788.

Schreyer, D., Schmidt, S. L., & Torgler, B. (2016). Against all odds? Exploring the role of game outcome uncertainty in season ticket holders' stadium attendance demand. *Journal of Economic Psychology, 56*, 192–217.

Schreyer, D., Schmidt, S. L., & Torgler, B. (2018). Predicting season ticket holder loyalty using geographical information. *Applied Economics Letters, 25*(4), 272–277.

Schreyer, D., & Torgler, B. (2021). Predicting season ticket holder no-show behaviour: More nuanced evidence from Switzerland. *Applied Economics, 53*(48), 5549–5566.

Seattle Seahawks (2022, August 25). *Seattle Seahawks and Lumen Field to Become First NFL Venue to Open a Food and Beverage Store Powered by Amazon's Just Walk Out Technology and Amazon One.* https://tinyurl.com/4bbpve2f

Shields, B., & Rein, I. (2020). Strategies to reimagine the stadium experience. *21st Century Sports: How Technologies Will Change Sports in the Digital Age*, 233–248.

Singleton, C., Reade, J., Rewilak, J., & Schreyer, D. (2021). How big is home advantage at the Olympic Games? https://doi.org/10.2139/ssrn.3888639

Spiegel (2023, April 26). *Fortuna Düsseldorf plant kostenlose Heimspiele* [Fortuna Düsseldorf plans free home games]. https://tinyurl.com/yckmv656

SportsPro (2023, January 23). *NBA and Meta to stream live games in 'NBA Arena' VR experience.* https://tinyurl.com/2p85duc4

Stieler, M., Weismann, F., & Germelmann, C. C. (2014). Co-destruction of value by spectators: The case of silent protests. *European Sport Management Quarterly, 14*(1), 72–86.

The Guardian (2022, June 4). *Abba Voyage review – a dazzling retro-futurist extravaganza.* https://tinyurl.com/4d9tefz5

The Verge (2023, January 6). *Sony and Manchester City are building a metaverse.* https://tinyurl.com/yc83frtc

Torgler, B. (2020). Big data, artificial intelligence, and quantum computing in sports. *21st Century Sports: How Technologies Will Change Sports in the Digital Age*, 153–173.

Union des associations européennes de football [UEFA] (2022). *The Business Case for Women's Football.*

Union des associations européennes de football [UEFA] (2023). *The European Club Footballing Landscape.*

Uhlendorf, K., & Uhrich, S. (2022). A multi-method analysis of sport spectator resistance to augmented reality technology in the stadium. *Journal of Global Sport Management.* https://doi.org/10.1080/24704067.2022.2155210

Van Reeth, D. (2023). The complexities of understanding reported TV audiences for live sports broadcasts. *International Journal of Sport Finance, 18*(1), 19–34.

VfL Wolfsburg (2023, March 26). Schon heute die digitale Welt von morgen entdecken [Discover the digital world of tomorrow already today]. https://tinyurl.com/ma585brd

Waldhof Mannheim (2022). Ticketaktion zum letzten Heimspiel des Jahres [Ticket campaign for the last home game of the year]. https://tinyurl.com/345ue8jd

Wilkesmann, U. (2022). Should I stay (at home) or should I go (to the stadium)? Why will some football supporters not return to the stadium after the COVID-19 pandemic in German Bundesliga? *Soccer & Society, 23*(8), 1069–1083.

Wired (2023, February 2). *Get Used to Face Recognition in Stadiums.* https://tinyurl.com/2xrkud5s

Dominik Schreyer is an außerplanmäßiger (apl.) Professor of Sports Economics at WHU – Otto Beisheim School of Management in Düsseldorf, Germany. In his mostly empirical research, he explores the role of sociopsychological factors in individual economic behavior and decision-making through the lens of professional sports. However, he also takes a keen interest in analyzing sports demand (e.g., football spectator no-show behavior). He has published 30+ articles in international peer-reviewed journals, including European Sport Management Quarterly, Games and Economic Behavior, and Technological Forecasting & Social Change. His Twitter handle is @schreyerforscht.

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 to be part of the experience (William 2015; Beall 2016; Northeastern 2014).

J. Pirker (✉)
Graz University of Technology and Game Lab Graz, Graz, Austria
e-mail: johanna.pirker@tugraz.at

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. 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.

References

Alonso Dos Santos, M., & Montoro Rios, F. J. (2016). Scale of spectators' motivations at soccer events. *Soccer & Society, 17*(1), 58–71.

Arshad, S. (2014). 10 most successful sports "Video Games" franchises. Retrieved from https://www.tsmplug.com/games/most-successful-sports-games-franchises/.

Augmented Reality in Sports. (2019). Retrieved from https://thinkmobiles.com/blog/augmented-reality-sports/.

Beall, G. (2016). 8 key differences between gen z and millennials—The Huffington Post. Retrieved from http://www.huffingtonpost.com/george-beall/8-keydifferences-betweenb12814200.html.

Bruce, M., & Regenbrecht, H. (2009). A virtual reality claustrophobia therapy system-implementation and test. In *Virtual Reality Conference, 2009, VR 2009* (pp. 179–182). IEEE.

Dede, C. (2009). Immersive interfaces for engagement and learning. *Science*, *323*(5910), 66–69.

De Meo, F. (2018). Rocket league reaches 50 million players worldwide in its fourth year. Retrieved from https://wccftech.com/rocket-league-50-million-players/.

ESA. (2019). 2019 essential facts about the computer and video game industry. Retrieved from https://www.theesa.com/wp-content/uploads/2019/05/ESA_Essential_facts_2019_final.pdf.

Formula 1. (2020). Retrieved from https://www.formula1.com/en/latest/article.formula-1-launches-virtual-grand-prix-series-to-replace-postponed-races.1znLAbPzBbCQPj1IDMeiOi.html.

Formula E Fanboost. (2020). Retrieved from https://fanboost.fiaformulae.com/.

FIFA.com. (2019). FIFA eWorld Cup 2019—News—FIFA eWorld Cup 2019 Grand Final generates record viewership. Retrieved from https://www.fifa.com/fifaeworldcup/news/fifa-eworld-cup-2019-grand-final-generates-record-viewership.

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. In *The International Scientific Conference Elearning and Software for Education* (Vol. 1, p. 133). Carol I National Defence University.

Matsuoka, H. (2014). Consumer involvement in sport activities impacts their motivation for spectating. *Asian Sport Management Review, 7*, 99–115.

MBA Syracuse. (2019). With viewership and revenue booming, esports set to compete with traditional sports. Retrieved from https://onlinebusiness.syr.edu/blog/esports-to-compete-with-traditional-sports/.

Mitic, I. (2019). Video game industry revenue set for another record-breaking year. Retrieved from https://fortunly.com/blog/video-game-industry-revenue/.

Mirza-Babaei, P. (2018). Beyond player experience: Designing for spectator-players. *User Experience Magazine, 18*(1). Retrieved from https://uxpamagazine.org/beyond-player-experience/.

Northeastern. (2014). Meet generation z—Full survey results. Retrieved April 16, 2017, from http://www.northeastern.edu/innovationsurvey/pdfs/Innovation_Summit_GenZ_Topline_Rep ort.pdf.

Ombler, M. (2019, September 4). 'It inspired a generation': Tony Hawk on how the Pro Skater video games changed lives. Retrieved from https://www.theguardian.com/games/2019/sep/04/ tony-hawks-pro-skater-playstation-games-skateboarding.

ÖRV (2020). 'Ritzinger und Machner gewinnen den historischen Auftakt der eCycling League Austria'. Retrieved from https://www.radsportverband.at/index.php/aktuelles/radsport-news/ allgemein/4832-ritzinger-und-machner-gewinnen-den-historischen-auftakt-der-ecycling-lea gue-austria.

Pirker, J., & Angermann, R. (2019). Tackling audience experiences in games. In *Game Developers Conference 2019*.

Singer, D. (2017). We are wrong about millennial sports fans. Retrieved from https://www.mck insey.com/industries/media-and-entertainment/ourinsights/we-are-wrong-about-millennialsp orts-fans#0.

Stahlke, S., Robb, J., & Mirza-Babaei, P. (2018). The fall of the fourth wall: Designing and evaluating interactive spectator experiences. *International Journal of Gaming and Computer-Mediated Simulations (IJGCMS), 10*(1), 42–62.

Strudwick, C. (2014). Watch live: Gamers battle out to win at record-breaking FIFA Interactive World Cup. Retrieved from https://www.guinnessworldrecords.com/news/2014/7/watch-live-gamers-battle-out-to-win-at-record-breaking-fifa-interactive-world-cup-58551.

The Bitmap Brother. Speedball. Game [Amiga]. (1988). Image works, UK.

VR training make Stanford kicker a hero: Strivr testimonial. (2016). Retrieved from https://www.strivr.com/resources/customers/stanford/.

Williams, A. (2015). Move over, millennials, here comes generation z. The New York Times. Retrieved from https://www.nytimes.com/2015/09/20/fashion/move-over-millennials-here-comes-generation-z.html?r=0.

Johanna Pirker is an Assistant Professor of Games Engineering at Graz University of Technology and Director of Game Lab Graz. Her research is focused on designing digital games and VR experiences to solve real-world problems. For her work, she was listed on *Forbes' 30 Under 30 list of science professionals*. Prior to academia, she worked in the games industry and still consults studios in the field of games user research. She spends her free time on her mountain bike, skiing, and in the boxing club. In her section, she combines her two passions: video game research and sports.

Technology Convergence

Sports in the Third Connected Age

Rishad Tobaccowala

Abstract

In this chapter, Tobaccowala looks back on how sports were impacted by the first two connected ages and forward to the key changes expected to sports fan experience, the monetization of sports, and the nature of sports in the Third Connected Age. He also explores the implications and ramifications of this new age for sports leaders. Finally, he outlines three key steps for success: changing thinking, investing in education, and focusing on partnerships.

We are living in a **Connected Age.** The biggest advance in connectedness has been the Internet, which started the *First Connected Age*. But we have lived through two connected ages and are now in the third. If you have an Amazon Echo or Google Home, for example, you have a *Third Connected Age* device in your home. They use AI, the cloud, and voice. In many countries, these devices are connected via 5G, though they are connected by wireless in the US.

Long before the internet, television supercharged sports and sports supercharged television viewing—connecting fans everywhere to their local sports teams while building the value of franchises and players. As society and sports moved through the connected ages, every advance transformed the fan experience, the monetization potential, and the nature of the sport itself.

Today, well past the *Second Connected Age* of television and streaming, we see the results: Mobile phones have made sports accessible to over 5 billion people enabling them to gather, chat, and discuss sports. Social media has further enhanced the fan experience as well as loyalty to teams and players. Now, as we

R. Tobaccowala (✉)
Rishad Tobaccowala LLC, Chicago, IL, USA
e-mail: rishad@gmail.com

enter the next generation of technologies from AI to AR/VR and 5G, we will see still more change in the world of sports.

Technology and sports have always been intertwined. Every advance in technology has helped transform the fan experience, the monetization potential, and the nature of the sport itself. This paper looks back on how sports were impacted by the first two connected ages and forward to the changes expected in the Third Connected Age.

1   The Third Connected Age

The First Connected Age began in 1989 with the birth of the World Wide Web. Though for many of us, our first experience was in 1993, with the advent of Mosaic, the first commercially available web browser.

In that first era of slow modems, we learned to navigate grey pages with blue links. The First Connected Age brought us two wonders: The ability to *connect to information* and the possibility to *connect to transact*.

In many parts of the world, Google and Amazon came to dominate the *connect to be informed* and *connect to transact benefits*, respectively. Search and e-commerce changed life. Amazon and Google are now two of the most valuable companies in the world.

In and around 2007, we entered the Second Connected Age. This era was marked by the first smartphones and scaled social networks. We could *connect to everybody*, *connect to entertainment*, and *connect all the time.*

Social, streaming, and mobile built on the First Connected Age and changed the world in many ways including a deluge of individualized, second-by-second data. Apple, Netflix, and Meta dominated by facilitating connections and joined Google and Amazon as the most valuable companies in the world.

The Second Connected Age allowed for the birth of new companies like Uber and Airbnb as they required mobile devices and social recommendations. But connectedness was a double-edged sword; micro-targeting based on information shared on social media allowed marketers to sell products and politicians and other folks to micro-target passions and influence elections, inflame and scale rage, and much more.

The second-order impact of each connected age is far greater than the technological impact. For example, search and ecommerce significantly hurt local newspapers and local retail stores, which changed the fabric of most small cities. Social media has influenced elections and significantly increased polarization as people can find and escape into their own bubbles.

We are now at the dawn of the Third Connected Age, which is driven by four new connections:

i. *Data connecting to data* or pattern matching and machine learning, which in 2023 is the most important flavor of AI-powered technologies. Examples include ChatGPT, Dall-E2 and Lensa Ai.

ii. *Much faster means of connecting,* which will be turbocharged by 5G.
iii. *New ways of connecting.* Today we connect by voice, and tomorrow we will connect in AR/VR.
iv. *New trust connections* built on mathematics like blockchain.

Due to COVID-19, the Third Connected Age was accelerated: For example, more people began to work from home and develop side gigs or side hustles where ownership of content via decentralized autonomous organizations (DAOs) was essential. According to a McKinsey survey of employed Americans, a remarkable 36 percent of employed respondents—equivalent to 58 million Americans when extrapolated from the representative sample—identified as independent workers post-pandemic; this figure represents a notable increase since the US independent workforce in 2016 was estimated at 27 percent of the employed population (Dua et al., 2022). The reverberations of the pandemic are likely to continue to re-make industry and society in ways we can now barely comprehend.

2   Sports in the Third Connected Age

Every aspect of sports will be impacted by the Third Connected Age technologies. As connections become faster, there are new ways for fans to connect to sports and each other.

There are three key ways sports will change in the Third Connected Age: The sports fan experience, the monetization of sports, and the nature of sports.

2.1   The Fan Experience

The First Connected Age enhanced the sports fan experience by making it easier to find and buy tickets to events and merchandise.

The Second Connected Age further enhanced the fan experience by adding the dimension of mobile phones. Fans could participate in new ways and teams could better engage via social media. In addition, streaming offered new options for viewing a spectrum of sports across time zones. For example, in its four seasons (to date) Netflix's "Drive to Survive" has been a massive hit, raising the sport's profile in the United States and introducing F1 to tens of millions of people.

The value of sports and streaming was highlighted by the bidding war for the Indian Premier League (IPL) cricket rights in India. The streaming and TV rights for the IPL, the world's richest cricket competition, were sold to Viacom18 for 3.05 billion USD for five years (beginning in 2023). Disney-owned Star India retained the TV contract for 3.02 billion USD. Combined, the two deals are more than double the 2.4 billion USD Star paid for the previous five seasons of the IPL.

The Third Connected Age will continue to expand the fan experience via new in- and out-of-stadium experiences, enhanced video experiences, and real-time betting. I will examine each in turn.

The new in-stadium experience will be facilitated by 5G connectivity in stadiums; it will allow fans to watch particular players on their mobile devices. They will experience a game everyone is watching and a game bespoke to them. The technology will also allow for in-seat ordering.

The new out-of-stadium experience is already facilitated by platforms like Roblox, an app that combines gaming, social media, and social commerce. Billing itself as the "ultimate virtual universe," Roblox allows users to socialize, build their own spaces, and even earn and spend virtual money. It has been utilized by musicians to create global music events in the virtual world attracting millions of fans. Also in the future, advances in VR will allow fans to be teleported into the stadium or even bring the stadium to them.

At its highest speeds, 5G will allow for far better video experiences both at home and on the road with zero buffering, fast download speeds, and the option to switch between streams. In addition, the increased capacity will allow for augmented reality (AR).

Increasingly, sports betting is growing in-stadium. With zero lag time and high speeds of 5G, there are opportunities for a spectrum of betting options. Fans will be able to bet on the next play—including whether the next pitch will be a strikeout—since there will be minimal delay from the bet to its confirmation. This will also allow betting platforms to create more betting occasions.

Some stadiums have already started experimenting with 5G. For example, Barcelona's iconic Nou Camp stadium is now the first in Europe equipped with a dedicated 5G network. Several wireless 360-degree cameras have already been installed and fans watching at home can watch the game using VR headsets. In the US, the AT&T Stadium in Dallas and the Golden 1 Center Arena of the Sacramento Kings are the 5G frontrunners. In Dallas, fans just have to hold up their 5G-enabled phones and immediately the stadium transforms into an arena with giant football players.

2.2   The Monetization of Sports

The First Connected Age brought search and e-commerce, which allowed fans to easily find events and buy tickets. In the Second Connected Age, tickets could be found, purchased, and displayed by phone. The social elements of the Second Connected Age allowed for greater monetization by incentivizing fans to encourage their friends to come to events by sharing their great experiences on social media and offering discounts and other inducements. Recently, monetization via sports betting has been abetted by mobility, which allows betting in the stadium and on the go.

5G technology will allow for new monetization streams in sports betting. But, an even bigger game changer is the ability to tokenize and sell ownership of many different sports assets on the value chain. The new trust connections of blockchain technology allows for scarcity, ownership, and trading of assets such as player cards in the digital space. One example is Autograph.io, which was co-founded

by Tom Brady. Autograph is a NFT platform that brings together the most iconic brands and legendary names in sports and entertainment to create unique digital collections and experiences. Sports stars can directly monetize their player persona not unlike the next generation of trading cards. It's unlikely, however, to stop at that.

In the music world, Lil Nas X leverages Royal.io to sell a portion of his streaming revenues via tokens. Big spenders get access to concert tickets and personal meetings.

Today, the Green Bay Packers are unique among sports teams because they are fan-owned. As we move into the future of sports, there is an opportunity to similarly re-think ownership, perhaps using tokens, so that fans can buy into ownership.

Blockchain will allow for many new ways to monetize sports, incentivize fandom, and raise funds for new types of sports and venues.

2.3 The Nature of Sports

The First Connected Age made sports much more global because people could watch games not broadcast on television. For example, I watched cricket in India over the Internet and could discuss games with people all over the world.

In the Second Connected Age, mobile and social media truly enhanced the Fantasy Sports experience and created opportunities to watch and feel connected to players playing electronic games like on Twitch, for example.

Every aspect of the sport will be impacted by the Third Connected age–from how people train to recruiting and refereeing. Just as the digital world gave birth to esports, the Third Connected Age will also create a spectrum of new sports.

2.3.1 Training

With tools like the Apple Watch, individuals have new ways to train, get feedback, and access and learn from a wealth of data. New Open AI and AR/VR technology will further accentuate these training capabilities. Sensors both on the body and in equipment will help us experience and learn from continuous feedback.

Some time ago, data-driven talent recruiting as depicted in *Moneyball*, for example, indicated that data was a key to sports. Now, with AI, what one can learn from the data and use it for will only expand.

2.3.2 Refereeing

Already, Hawkeye technology, a camera system that traces the ball's trajectory during the game, helps referees make better decisions. It is the most advanced officiating tool used in sport and is used across many sports. With enhanced AR and 5G, these technologies will only get better. Increasingly, decisions will be outsourced to machines, which will be able to make the most precise call.

2.3.3   New Types of Sports

Combining or integrating sports and technology will birth new sports and attract new, young participants. It's likely that these new "technosports" will rapidly gain market share. A good example is HADO, which is already incredibly popular in countries such as Japan and Singapore. HADO is a sport that lets players strap on head-mounted displays and armband sensors to wield energy balls and shields, bringing the virtual world into reality on a real-world court.

3   Implications and Ramifications of the Third Connected Age for Sports Leaders

Just as the Third Connected Age creates the possibility of new fan experiences, new ways to monetize sports, and even new sports, it will impact the business of sports in a variety of ways. The changes—from enhancing and attracting new talent and forcing businesses to become technology savvy or focused and more global—will require sports owners, leaders, and officiating officials to re-think and re-imagine their own jobs and businesses.

3.1   Increasingly, Sports Will Be a Technology Enterprise

Sports will increasingly run like technology companies requiring significant capital investments to ensure teams have the best equipment and that sporting facilities are up to date. The proportion of data scientists, engineers, and technology partnerships will also grow to be a significant part of employees and spending.

Data-driven sports have already changed the front and back office of sports organizations and a world of tokens, AI, and more will further revolutionize team structures and, potentially, ownership. For example, technology entrepreneurs such as Mark Cuban have already leveraged their wealth into sports team ownership.

3.2   Sports Will Be Increasingly Global

Sports have grown and changed alongside communication capabilities—from radio to television and, now, the Internet. The Internet of the Third Connected Age is truly global with on-demand and connected devices allowing for sports anywhere to be viewed anytime and anywhere.

Because of the reduced cost of technology and computing and the availability of new ways of funding (crowdfunding to tokens), it will only become easier for people all over the world to influence and be more involved with sports.

3.3 Rights Management of Every Type Will Be in Flux

Modern AI sweeps the net for data and images and then creates new types of content. Because of this, the likeness of sports teams and stars will need to be managed in new ways. In addition, as more leagues launch their own media channels and deal with a new range of distribution channels (TikTok, Amazon, Google, Tencent, etc.) the idea of negotiating with a few networks once every few years will seem quaint.

The music industry, again, provides an example. Today, some of the music industry's biggest negotiations take place with TikTok, which allows fans to sample music and create overnight hits. But, today's sampling of music is nothing compared to the sampling of likeness and sports insignia and insertion of players into VR simulators, for example.

3.4 Sports Stars Will Grow Even Bigger and Demand a Greater Share of Revenue

Today, the biggest social media stars tend to be musicians and many have tens of millions, if not hundreds of millions, of followers. As sports stars become more comfortable with next-generation tools to create, distribute, and monetize sports, they will increasingly be large media companies themselves. A shift in the balance of power from sports owners to sports celebrities—where players wish to own and not just perform—will continue to grow.

3.5 A Plethora of New Sports Leagues are Likely

Just as gaming created a world of esports, modern AR and VR will result in new types of sports and, possibly, sports leagues. What is particularly intriguing is that in a world of web3, where power is likely to be increasingly decentralized and open, a new generation of fans and owners may create their own leagues.

In his paper in *Sports Management Perspectives*, Kenneth Cortsen predicts that web3, driven by the blockchain, will make sports more decentralized and open (Cortsen, 2022). The gatekeepers at Google and Facebook and even the leagues will not stop athletes and fans from creating new leagues and sharing revenues between fans and athletes that would have gone to an ecosystem of middlemen.

3.6 New Types of Sports Security

Security has always been a major factor in sports including controlling the crowd control and maintaining the safety of fans and players. This physical security has extended to include digital security: to make sure that mobile and other tickets are valid and betting platforms are not hacked.

Cyber security has become more important. In a world of AI, we are likely to deal with deep fakes. When a sport is played in AR and VR, the entire sport—not just access to it or its data—needs to be protected. Every team and sports body will need to up their game to be able to monitor, secure, and audit every aspect of the sport and the sporting experience.

4   Three Keys to Managing Sports in the Third Connected Age

In order to continue to thrive in the Third Connected Age every leader, franchise, and media company will have to re-think and re-consider their strategies and tactics as they move forward so as to remain relevant. While there will be many areas to re-think and re-consider, I outline three keys to a thriving future below.

4.1   The Future Does Not Fit in the Containers of the Past

The range, variety, and availability of sports will explode in the Third Connected Age, which will challenge every manager to expand and re-think in a world of no boundaries, no time periods, and the shift of control to the fan and the athletes. Sports used to be played in a place and a time. Modern technology like AR/VR means sports can now be disconnected from a space. With an interconnected world and more and more fans creating sports, there is also a collapse of time periods and seasons for sports. Sports fans will have a far greater array of sports: They will be able to watch both in real-time and on-demand sports played in the physical and the virtual world.

A new mindset is necessary—one that forgets what has come before and imagines what is possible constrained only by the law, technology, and economics. When there is a big shift, adapting to the old never gets to the potential of what is possible. Disruption happens when people think with a clean sheet of paper.

The question will be: If one started again with all the assets, no liabilities, and just these constraints, how would one re-imagine one's career, franchise, media company, etc.?

4.2   Invest in Education

All leaders need to spend time being trained about the new technologies of the Third Connected Age so they will be better able to understand and manage the possibilities. Delegating decisions without understanding the implications or hoping to delay change until one steps down are not viable options.

Investing in education will include bringing in new skills and talent from those conversant with AI and VR/AR, learning how to manage talent who will have more power, and finding ways to satisfy and monetize a fan base who will have more options and opportunities to spend their dollars.

4.3   A Partnership Orientation

The sports industry is already partnership-oriented, but the industry of the future will be even more so. Everyone will need to plug and play with experts in the components of AI, 5G, blockchain, metaverse, virtual reality and more. The sports stack will be supplemented by the tech stack.

In particular, the tech stack will help determine how sports teams can license or create new possibilities in the world of AR and VR and find ways to give share ownership of new initiatives with early adopting fans.

5   Sports in the Third Connected Age, A Summary

Each advance in technology has transformed the fan experience, the monetization potential, and the nature of the sport itself. In many ways, The Third Connected Age continues on this path: technology continues to impact and evolve sports.

It is possible that this next shift will be revolutionary rather than evolutionary because the new technologies extend and expand sports in ways that redefine foundational beliefs, particularly in regard to ownership and the collapse of time and space. In terms of ownership, fans, and athletes, as opposed to leagues and businesses, will play a major ownership role. Without the requirements of time and space, AR, VR, and 5G will facilitate the creation of fantastic new sports; we may find ourselves watching virtual players playing in virtual space.

Despite these changes, it's clear that sports will continue to be key to culture, business, and society. There is potential that their influence will only grow in the new age as more fans in more places will be able to play, interact with, and own the sporting experience.

References

Cortsen, K. (2022). *The impact of WEB3 on the business of sports.* Kenneth Cortsen. Retrieved April 10, 2023, from https://kennethcortsen.com/the-impact-of-web3-on-the-business-of-sports/.

Dua, A., Ellingrud, K., Hancock, B., Luby, R., Madgavkar, A., & Pemberton, S. (2022). *Freelance, side hustles, and gigs: Many more Americans have become independent workers.* McKinsey & Company. Retrieved April 10, 2023, from https://www.mckinsey.com/featured-insights/sustainable-inclusive-growth/future-of-america/freelance-side-hustles-and-gigs-many-more-americans-have-become-independent-workers.

Rishad Tobaccowala is the author of *Restoring the Soul of Business: Staying Human in the Age of Data* and the weekly thought-letter *The Future Does Not Fit in the Containers of the Past*. He is also a speaker and advisor on change, future trends, and transforming workforces. Formerly, he was the Chief Strategist and Chief Growth Officer of Publicis Groupe.

Navigating the Web3 Landscape: A Forward-Looking Perspective on the Future of Sports Business for Athletes, Consumers, and Management

Amir Raveh

Abstract

As the world continues to progress into the digital age, sports are also evolving into a new landscape. Web3 technology is one of the most exciting developments in the digital realm and has the potential to revolutionize the sports business as we know it. In this chapter, Raveh explores the future of sports in the web3 era–focusing on future athletes, sports consumers, and management. He begins by introducing GenAlpha and community building in the sports business then dives into the fundamentals of web3 technology and its potential applications in sports. Finally, he discusses the impact of web3 technology on sports consumption, athletes, and management, as well as its potential for growth in the global sports technology startup scene.

1 Introduction

Sports have always been an integral part of human culture. Even in ancient times, nations held games and competitions to celebrate their citizens' physical prowess. From the beginning of the Olympic Games to the present day, when sports superstars perform incredible athletic feats the excitement has yet to dim.

Over the past two decades, technology has revolutionized the sports world, changing the way we watch, play, and monetize sports. From social media and streaming services to wearables, biometrics, and data analytics, new technologies have transformed the sports landscape. But the next evolution in sports technology is already here, and it's poised to change the game forever.

A. Raveh (✉)
HYPE Sports Innovation, London, United Kingdom
e-mail: amir@hypesportsinnovation.com

Imagine donning virtual reality glasses and finding yourself transported onto the field, standing right next to your favorite athletes. You can feel the excitement of the game pulsing through your veins as you follow every move they make. With web3, this type of experience will be possible for fans. But it's not just about the immersive experience for the fans; the advent of future technologies will revolutionize the way athletes train and compete and provide brand-new opportunities for sports entities to expand their revenue streams.

The current state of the sports business is highly competitive, with traditional sports organizations such as teams, leagues, and media outlets facing new challenges from emerging digital platforms and technology companies. The rise of web3 technology presents both opportunities and challenges for sports businesses, and it is poised to revolutionize the way sports are played, viewed, and managed. We are currently in the midst of a technological revolution that is transforming the world of sports as we know it.

In this chapter, I will dive into the incredible opportunities and challenges that lie ahead and explore how they will impact the world of sports business–from athletes to fans and management. So buckle up and get ready for a thrilling ride into the future of sports!

2   Understanding GenAlpha and Building Community

As sports organizations look to the future, it is essential that they understand the needs and unique characteristics of their younger audiences, especially Generation Alpha (GenAlpha), or those born after 2010. To capture this young generation, sports entities should consider the development of immersive technologies, such as fully interactive virtual reality experiences, augmented reality features that allow fans to overlay statistics onto live games, and even holographic displays that bring players and games to life in a whole new way.

Furthermore, as GenAlpha grows up and becomes more digitally savvy, sports organizations will need to continue to find new ways to engage them beyond traditional sporting events. This could include expanding esports leagues and other digital gaming options, as well as creating more personalized experiences that cater to the unique interests and preferences of each fan.

Sports organizations can leverage technology to create immersive experiences, such as virtual reality and gamification, and offer fans customized merchandise and VIP packages. For example, the NBA has partnered with Oculus to provide fans with a virtual courtside experience that simulates the feeling of being courtside.

In addition, esports has seen a huge uptick in recent years, especially with Gen Z and GenAlpha consumers. Accordingly, sports organizations such as the NBA and NFL have created their own esports leagues, giving fans a new way to experience sports and engage with their favorite teams. To build a strong community and increase fan loyalty, sports organizations must create a sense of belonging among fans.

By fostering a shared sense of identity, values, and purpose, sports organizations can create a loyal fan base that generates revenue and enhances their brand image. Social media is a powerful tool to achieve this, as sports organizations can use it to create personalized experiences and connect with fans on a personal level.

In summary, sports organizations that want to succeed in the twenty-first century need to understand how technology is changing sports and how they can address the needs of their younger audiences. By embracing technology and building a strong community, sports organizations can thrive in the digital age and connect with fans in new and exciting ways. The future of sports business is promising, and it's up to sports organizations to embrace change and lead the way forward.

3 The Basics of Web3 Technology and Its Possible Applications in Sports

Web3 technology has the potential to transform the sports industry in a variety of ways. As a basic definition, web3 technology is a term used to describe the next generation of the internet. It is a decentralized web built on blockchain technology. One of the key features of web3 technology is its emphasis on decentralization, which eliminates the need for intermediaries. There are many potential applications in the world of sports including fan engagement, sports betting, new viewing experiences, and analyzing sports data; I will examine each in turn.

With web3 technology, sports businesses can create a decentralized ecosystem where athletes, fans, and sponsors can interact directly with each other. This has the potential to fundamentally change the way sports business is conducted. For example, a potential application is in the area of fan engagement. With web3 technology, fans can own and trade digital assets such as sports memorabilia or tickets using blockchain technology; this could lead to a more transparent and secure marketplace where fans can buy and sell these assets.

Another potential application of web3 technology in sports is in sports betting. With the use of smart contracts, web3 technology could enable the creation of decentralized sports betting platforms that are transparent and secure. This could eliminate the need for traditional sports betting platforms, which often charge high fees and are prone to fraud.

Web3 technology could also have a significant impact on the way we watch sports. With the advent of virtual reality (VR) and augmented reality (AR) technologies, fans could have a more immersive experience while watching sports. Web3 technology could enable the creation of decentralized VR and AR platforms where fans can interact with each other during live sporting events in real time.

With the use of smart contracts and blockchain technology of web3 technology, sports teams and organizations could store and analyze data in a more secure and transparent way. This could lead to a more accurate and insightful analysis of player and team performance, which could ultimately lead to better decision-making.

In summary, web3 technology has the potential to transform the sports industry in a variety of ways. From fan engagement to sports betting and sports analytics, the possibilities are seemingly endless. However, it is important to note that the adoption of web3 technology in sports depends on a variety of factors including the legal framework and user acceptance. Nevertheless, it is clear that web3 technology will play an important role in shaping the future of sports in the digital age.

4   The Future of Sports Consumption in the Web3 Era

The rise of web3 technology will change the way sports are consumed by GenAlpha and beyond. It will create decentralized, personalized, and engaging experiences for fans, while opening up new revenue streams for sports organizations. With web3, fans have more control over their sports experience. They can personalize content, connect with other fans, and engage with their favorite teams and players in more meaningful ways.

Currently, sports media is dominated by traditional broadcasters who control the coverage and delivery of sports content. Web3 technology will enable decentralized media platforms that allow fans to have more control over what they watch, when they watch it, and how they pay for it. Fans will be able to access sports content directly from teams, leagues, and players, bypassing traditional broadcasters and eliminating the need for middlemen. This will create new revenue streams for sports organizations while providing fans with a more personalized and, potentially, cost-effective way to consume sports content.

Another area where web3 technology will have a major impact is streaming. The rise of streaming platforms like Netflix, Amazon Prime, and Disney + has already disrupted the traditional broadcasting model. Web3 will take it a step further. With web3, streaming will become more decentralized; and fans will have more influence over the type of content they want to watch and how they consume it. Fans will be able to participate in the creation of sports content through live streaming, virtual reality experiences, or interactive games. This will create a more engaging and immersive experience for fans and blur the lines between sports, entertainment, and gaming.

Finally, web3 technology will transform fan engagement. Currently, fan engagement is limited to traditional social media platforms such as Facebook, TikTok, Twitter, and Instagram. However, with web3, fan engagement will become more decentralized and individualized. Fans will have more control over the type of content they see and how they interact with other fans, teams, and players. Fans will be able to create their own social media platforms, connect directly with their favorite teams and players, and even invest in their success through cryptocurrency and other blockchain-based assets. This will create a more loyal and engaged fan base, as fans will have a more direct stake in the success of their teams and players.

In summary, web3 technology promises to revolutionize the way sports are consumed by enabling seamless interaction between fans, teams, and players. It will

create a decentralized, personalized, and engaging experience for fans, while opening up new revenue streams for sports organizations. The impact on sports media, streaming, and fan engagement will be significant, blurring the lines between sports, entertainment, and gaming. The future of sports in the web3 era promises to be exciting, innovative, and transformative.

5   The Impact of Web3 Technology on Athletes

Web3 technology offers athletes new ways to train, manage their workload, analyze their performance, and take ownership of their data and brand. In this section, I will explore how web3 technology will impact athletes in the digital age, from training and workload management to performance analytics and athlete ownership.

One area where web3 technology is likely to have a major impact on athletes is training. With web3 technology, athletes can access a variety of training tools and resources that were previously unavailable. For example, athletes can use smart contracts to enter into training agreements with coaches and sports trainers. These agreements can be automated using blockchain technology to ensure that both parties meet their obligations. In addition, web3 technology can be used to create virtual training environments that mimic real-world conditions so that athletes can train more effectively and efficiently.

Load management is another area where web3 technology will change the game for athletes. Load management is the management of an athlete's workload to ensure they do not suffer from fatigue, injury, or burnout. With web3 technology, athletes can manage their workload more effectively using smart contracts. For example, athletes can limit the number of workouts they do each week, with smart contracts automatically enforcing those limits. In addition, web3 technology can be used to monitor an athlete's physical and mental well-being, and coaches and sports trainers can adjust the athlete's workload accordingly.

Performance analysis is another area where web3 technology will revolutionize sports. Athletes can use blockchain-powered platforms to collect, store, and analyze performance data. This data can be used to identify areas where an athlete needs to improve and create customized training programs that target those areas. In addition, web3 technology can be used to create digital identities for athletes to present their performance data to potential sponsors and fans.

Of greatest potential impact for athletes is web3 technology-enabled control over their data and brand. With web3 technology, athletes can use blockchain-powered platforms to create and manage their digital identities. These digital identities can include information such as performance data, social media presence, and advertising contracts. In addition, athletes can use smart contracts to create transparent, secure, and enforceable sponsorship agreements. This gives athletes greater control over their brand and allows them to receive a greater share of the value they create.

Web3 technology is set to have a significant impact on sports in the digital age. With its decentralized, open-source, and user-driven infrastructure, web3 technology offers athletes a new set of tools and resources that can help them train, manage their workload, and analyze their performance. In addition, web3 technology provides athletes with the ability to better control their data and their brand, and receive a greater share of the value they create. As web3 technology continues to evolve, we can expect to see more innovation in the sports industry and new opportunities for athletes to thrive.

6 The Future of Sports Management in the Web3 Era

The advent of web3 technology has the potential to create a paradigm shift in sports management and business operations. Web3 has the potential to transform the sports industry by providing a decentralized platform for transactions, data exchange, and ownership. The sports industry has already embraced digital transformation in many aspects of the industry, but web3 is expected to play a critical role, particularly in the area of sports management.

One of the most important impacts of web3 technology for sports management is fan engagement. With web3, fans can participate in the ownership and management of their favorite sports teams; enabled by blockchain technology, fans can purchase tokens that represent ownership stakes in a team. Fans could then use these tokens to vote on team management decisions, such as hiring coaches and players, and branding and marketing strategies for the team. Teams could also better align their goals and strategies with the interests of their fan base; this could lead to greater fan engagement and loyalty, which could translate into higher revenues for teams.

In addition to fan engagement, web3 technology could improve the efficiency and transparency of sports companies. By using blockchain technology, sports teams could streamline their payment systems and ensure that payments are made on time and securely. Blockchain technology could also provide a transparent record of all financial transactions, which could reduce the risk of fraud and increase accountability for team management.

One important area that could be improved is ticketing technology. Fans could buy tickets directly from teams and athletes via blockchain-powered platforms, without the need for intermediaries such as ticketing agencies. This model of selling tickets directly to fans has the potential to eliminate the problem of ticket scalping, as tickets are sold at a fair market price and cannot be resold at inflated prices. In addition, web3 technology can be used to create smart contracts that enforce a fair distribution of tickets and prevent scalpers from buying up large quantities of tickets and reselling them for profit.

Another area where web3 technology could have a significant impact on sports management is data sharing. By using decentralized platforms, sports teams could securely share data with other teams, leagues, and sports industry players. This

could lead to better collaboration and innovation in sports management, as teams could learn from each other and share best practices.

The use of blockchain technology in sports management could also improve the management of player contracts and rights. With blockchain, contracts could be stored in a secure and transparent ledger, which could reduce the risk of disputes and ensure that players' rights are protected. This could lead to a more stable and transparent market for player transfers, benefiting both players and teams.

There are, however, potential challenges and limitations to the use of web3 technology in sports management. One challenge is potential regulatory uncertainty, as web3 technology operates in a decentralized and largely unregulated environment. Therefore, the use of blockchain technology in sports management may present legal and regulatory challenges, particularly in the areas of ownership and privacy.

Another challenge is the potential for technological barriers to adoption. While web3 technology has the potential to revolutionize the sports industry, it is still in the early stages of development. Adoption of this technology may require significant investment in infrastructure and training, especially for smaller sports organizations.

Web3 technology has the potential to transform sports management and business operations. Decentralized management models enabled by blockchain technology could improve fan engagement, transparency, and efficiency in the sports industry. However, there are also challenges and limitations to the adoption of web3 technology, particularly with regard to regulation and technology adoption. Despite these challenges, the potential benefits of web3 technology in sports management are significant and its adoption is likely in the coming years.

7 Applications of Artificial Intelligence in the Web3 Era

The advent of web3 and the rise of decentralized applications has opened up new opportunities for the sports technology industry. Coupled with the potential of Artificial Intelligence (AI), the possibilities become even more exciting. AI has the potential to revolutionize the sports technology industry in the coming years–impacting not only athletes, but also sports consumers and management.

For athletes, AI can improve performance through personalized training and conditioning programs based on real-time data. It can also help coaches analyze game footage and make strategic decisions during games. In addition, AI can help athletes avoid injuries by predicting weaknesses and preventing them before they occur based on biometric data and injury history.

For sports consumers, AI will provide a more immersive and personalized experience such as tailored viewing options based on preferences and interests. AI-powered chatbots can also provide instant customer service by answering queries and providing real-time updates. In addition, AI can improve fan engagement by providing real-time statistics, highlights, and interactive games.

For sports managers, AI can provide valuable insights and analytics that help with player recruitment, scouting, and performance evaluation. AI can also

improve operational efficiency by automating tasks such as scheduling, ticketing, and marketing. In addition, AI can help generate revenue through personalized advertising and sponsorships based on fan data and behavior.

Integrating AI into the sports technology industry, however, is not without its challenges. One concern is the potential bias of AI algorithms, which can perpetuate inequities in player selection and recruitment. Another concern is the ethical use of biometric data, as some experts worry that the collection and analysis of this data could violate players' privacy rights.

Despite these challenges, the future impact of AI on the sports technology industry is immense and the possibilities are endless. As technology continues to evolve, AI will play a critical role in changing the way we watch, play, and manage sports. It is likely that AI will continue to shape the future of sports technology and pave the way for new opportunities and innovations.

8   Possible Challenges in the Web3 Era

Like any new technology, the adoption of web3 presents some challenges for athletes, management, and consumers. One of the biggest challenges for athletes is the potential loss of control over personal data. With web3 technology, athletes could be forced to share personal data on a decentralized network; this could lead to privacy and security issues. In addition, the use of smart contracts in web3 technology could eliminate the need for intermediaries such as agents and lawyers, which could impact athletes' bargaining power in contract negotiations.

For sports business owners, one of the challenges of web3 technology is the need to adapt to new business models and revenue streams. The shift to decentralized ecosystems could disrupt traditional revenue streams, such as ticket sales and broadcast rights, and impact the financial stability of sports organizations. In addition, managing fan engagement could be challenging on decentralized platforms as there may be a lack of control over fan behavior and interactions.

For sports consumers, the challenges of web3 technology lie in the need to navigate a complex and unfamiliar ecosystem. Decentralized platforms can be difficult to access and use and there may be a lack of trust in new and unproven platforms. Additionally, the use of cryptocurrencies and other web3-specific tokens could lead to issues with volatility and security, which could affect consumer confidence in these platforms.

Overall, the challenges of web3 technology in sports are significant, but they can be overcome with careful planning, collaboration, and innovation. By working together to address these challenges, athletes, management, and consumers can realize the full potential of web3 technology and create a more equitable, transparent, and engaged sports ecosystem. By embracing web3 technology, sports businesses can stay ahead of the curve and create new opportunities for athletes, fans, and management.

9   A Brief Look at Sports Technology Startups in the Web3 Era

Several sports technology startups are currently emerging in the web3 space, each with their own goals for and potential contributions to the future of the sports industry. These companies are poised to address several of the issues and challenges mentioned in this chapter that have plagued the sports industry for years. Among these startups are companies that aim to directly impact athletes, consumers, and sports management.

For athletes, there are several sports technology startups that are already making a significant impact. For example, SAIVA is revolutionizing soccer training through the use of VR technology to replicate real-world gameplay and guide players through cognitive drills to develop their skills. JuniStat uses AI coaching analytics to identify young soccer talent. In addition, Respo Vision's AI and optical tracking system automatically collects player movements from every single camera recording of a sporting event. This data can be used to gain new insights into performance, tactics, and scouting, and provide viewers with an immersive 3D sports experience.

Companies like Alphaa.io and Medalio are solving sports management challenges by creating secure blockchain payment management systems that prevent fraud and increase ROI. Companies like CounterTEN and CollectID are developing blockchain technology to ensure secure and tamper-proof ticketing, reduce fraud, and improve fan sales.

Finally, for consumers, Fansea and NFT Labs are creating authentic and immersive digital fan experiences in the web3 world. CounterTEN is developing NFTs for the real world, such as events, VIP access, and retail promotions. Overall, these startups have the potential to shape the future of the sports industry by addressing various problems and providing innovative solutions.

The growth potential in the global sports technology startup scene is enormous. In the web3 era, startups focused on blockchain, VR, AR, and AI are expected to flourish. As technology continues to evolve, we can expect further innovation and change in the sports industry, creating new opportunities for sports businesses to grow and succeed in the web3 era.

10   Conclusion

Looking into the future, I envision a world where fans can connect with their favorite teams and players in ways that were once unimaginable–whether it's through virtual reality experiences that simulate the feeling of being on the court or field or through peer-to-peer marketplaces where fans can buy and sell NFTs that representing iconic moments in sports history.

Beyond technology, I believe that sports have the power to bring people together and inspire positive change in the world. Sports can unite communities, break down barriers, and teach valuable life lessons about teamwork, perseverance, and

sportsmanship. As we continue to innovate and embrace new technologies in the sports industry, let us not forget the impact that sports can have on peoples' lives and the world at large.

I am optimistic about the future of sports and the role that web3 technology will play in shaping it. Let us continue to innovate and push the boundaries of what is possible, while always remembering the fundamental values that make sports such a powerful and meaningful part of our lives.

Amir Raveh is a serial entrepreneur, investor, and the founder of HYPE Sports Innovation, the largest global sports innovation ecosystem. HYPE S.I. helps startups and entrepreneurs in the sports industry by providing funding, mentorship, and connections to leading sports organizations worldwide. HYPE partnered with New York University to launch the first blockchain accelerator program in 2018, a move that has been instrumental in the development of web3 technologies in the sports industry. As an advocate for the potential benefits of decentralized platforms, Raveh has spoken at numerous conferences and events on web3 technologies and solidified his position as a thought leader in the sports technology industry.

Imagining the Future of Fandom

Shelly Palmer

Abstract

In this guided exploration of the future fan experience, Palmer first offers advice on what should be prioritized—from the fan and the story to different levels of innovation. Next, he explores the technology available and possible to make the experience entertaining, seamless, and safe. Finally, he explores the data management systems necessary. "What's next?" he asks. It's up to you!

1   Imagining the Future Fan Experience

If there were no technological or financial restrictions, how would you want to attend a sporting event or a concert? What could "attending" mean? Would you want to point to a player on the field and see or hear his latest stats? Would you want your seat in the stadium to recognize you and understand your VIP status? Would you want access to the data the various coaches were using during the game? Would you want to play more realistic fantasy sports or have a digital twin of your game-worn collectible merchandise in a virtual world? Would the star players appear to you as a full-motion hologram, an avatar, or a synthetic human?

I encourage you to imagine your own future fan experience. Make a list.

Got it? Great. No matter what's on your list, here are just a few things to keep in mind to bring your future fan experience to life:

S. Palmer (✉)
The Palmer Group, S.I. Newhouse School of Public Communications, Syracuse, NY, USA
e-mail: shelly@shellypalmer.com

i Fan first

The most important thing about your list of future fan experiences is that they put the fan first. While every fan is unique, when fans are asked what they want most, there's a common answer: to be more deeply engaged with what they love.

ii Sports is storytelling at its best

Any future fan experience must stay focused on the story arc of the sport. We know the place (the setting). We know the players (the characters). We know the rules (the plot). We know the three possible conflicts (man against himself, man against man, man against nature).

All sports contain every aspect of the storytellers art: The subplots (personal stories), flashbacks (past performances and replays), foreshadowing (hints of plays to come), character arc (player development over time), etc., make the story. And, every sporting event has a clear beginning, middle, and ending and includes a rising action, climax, and falling action.

iii What to Look Out for

As you imagine the future of fandom, do your best not to create solutions in search of problems. Sports are popular because they are perfectly evolved to capture our imaginations. Professional sports are so perfectly suited to our experiential needs that we can just stand on the sidelines and become fully immersed in a game.

Therefore, for new, data-driven technologies to be meaningful, they need to enrich and enhance the fan experience. If you don't know how you could have possibly enjoyed a sport before your (insert your invention here) technology was added, then add it. But if you're just adding tech because you can, maybe you shouldn't.

iv Routine innovation

While imagining the future of fandom, it is helpful to remember that small, incremental improvements add up to huge improvements over time: slightly better graphics that are just a bit more readable, a slightly better way to deliver food at a stadium, a slightly faster payment gateway, etc. can mean a better experience now. Creating a culture of continuous improvement may be the easiest route to increased fan engagement and happier fans.

v Disruptive innovation

Routine (incremental) innovation is table stakes. Everyone who is serious about gaining a competitive advantage invests in it. But we are in an age of exponential technological improvements and we are learning about new, disruptive innovations almost daily. The shifting video landscape, new forms of value exchange, and

increased economic pressure are just a few of the forces that are driving the need for both disruptive and radical innovation. As the saying goes, it's better to disrupt yourself than have someone else do it for you.

2   Technology

Now that you have your list and know what to keep in mind, let's take a look at the technology that can make it possible. Centering on the consumer and empowering them, the technology will have to be built to make the experience entertaining, seamless, and safe.

i Empowered consumers

In order for future fans to experience the amazing things on your list, they will need to be technologically empowered to participate in the experience. This may mean having a smartphone or, possibly, eyewear that will enable augmented reality projections. The projections may include audio via headphones, earbuds, or bone-induction audio transducers. Most experiences will also include some kind of haptic feedback using clothing or by directly stimulating the nervous system. It may also include projectors, flat screens, lighting arrays, or other types of audio/visual technology you might use to create your imagined enhanced environment. No matter the experience, consumers will need the proper kit to take advantage of your creativity.

But do fans want to use technology to enhance their experiences?

A study from December 2019 found that 40% of fans were watching live matches in VR headsets to simulate the in-stadium experience (Gough, 2022); and nearly as many were utilizing multiple camera angles to watch the match (39%) or facing off against AI bots to predict how the match would turn out (38%). Many fans also used tech to enhance their experience via added insights and behind-the-scenes action (36%) or rewatched previous matches in 3D via an app (34%).

While many fans are already connected, studies show mixed feelings about VR and sports (Statista Research Department, 2022).

ii Network infrastructure

Today, most people walk around with several radios in their pockets. An average smartphone can connect to 5G UWB, 5G, LTE (4G), Wi-Fi, Bluetooth, NFC, and GPS, to name a few. In order to connect to the owner of such a device, you must have the wireless network infrastructure to support your use case.

One extraordinary example of "future fan ready" infrastructure can be found at SoFi Stadium in Los Angeles (Kapustka, 2022). Its network has 2,400 antennas and 3,200 remotes and is capable of covering all licensed spectrum bands from 600 MHz to 6 GHz. It can handle Wi-Fi consumption measured in terabytes of

data per hour. In non-technical terms, fans at SoFi can enjoy virtually unlimited use of their devices.

In 2021, an all-time high of 54.4% of internet traffic traveled over mobile phones (2023). This is no surprise as 4K (UHD) video is considered the most exciting current feature (Andre, 2023).

iii Privacy policies

If you've ever signed into a website or app using Google or Facebook (instead of a unique username and password), you've used a version of single sign-on (SSO), a market that has seen incredible growth in recent years. Research found that the SSO market grew to approximately 1.6 billion USD in 2021, a growth rate of 89 percent (Bass, 2023).

In some cases and on some devices, your mobile browser will keep this data in memory and you will remain signed into sites and apps until you sign out. While Apple loves apps, it hates websites; on iOS devices, Safari and Chrome cannot store the data needed to keep you signed in to a website once you close your browser. (Android users do not have this problem.) In any event, your fan experience of the future will have to provide a way for fans to sign in and stay signed in.

While we're thinking about signing in to apps and websites for your new fan experience, we should acknowledge that all privacy policies will have to be adhered to. Data privacy and protection rules will likely be different in different regions of the world, but every fan experience will have to respect local privacy laws.

A recent Gartner report found that 65% of the world's population will have modern privacy regulations protecting personal data by 2023, a number that has skyrocketed from 10% in 2010 (Riojas, 2022). In 2021, U.S. state legislatures proposed or passed at least 27 online privacy bills (Rahnama & Pentland, 2022), regulating data markets and protecting personal digital rights, while 75% of the world's countries have drafted or enacted data privacy regulations (as have 33 U.S. states) (2021).

iv SSI (Self-Sovereign Identifiers) Versus FIDO (Fast IDentity Online)

But, what if your future fan experience allows for more than one app or more than one experience to be offered at the same time in the same location? Or, what if you need to keep the fan logged in when the fan leaves the virtual or physical venue?

The concept of passwordless, cryptographically protected digital identification, has been around for a very long time. Today there are two competing technologies offering differing visions for our potential future digital identities: FIDO2, a specification from the FIDO Alliance, and SSI, a catchall phrase for a group of decentralized identity schemas.

Improved and enhanced security is a vital mission as humans are notoriously bad at using secure passwords, leading to data breaches and other security nightmares. A recent study found that more than 80% of breaches involve brute force or the use of lost or stolen credentials (2023). Many companies are attempting to combat this and make online life more secure; in late 2022, Google rolled out support for passkeys in Chrome Stable M108 (Sarraf, 2022). Enhancing privacy and security will be vital in a decentralized world.

FIDO's mission is to eliminate the password and make multi-factor authentication (MFA) easy, fast, and ubiquitous. The standard is singularly focused on security. Google brags, "On the employee side, there has not been a successful phishing attack against Google's 85,000 + employees since requiring use of FIDO security keys" (2021).

But FIDO2 is a centralized system, and while it does a wonderful job with security, it does not offer individuals complete control of their own data.

On the other hand, SSI is a set of open digital identity standards that gives individuals control over the information they use to prove who they are. It can be used to exchange data between issuers, holders, and verifiers without the involvement of any central authority.

You can think of your SSI as a non-transferable, non-fungible token (NFT) or smart contract that allows you to choose what data you wish to reveal. These NFTs can then be verified by anyone you authorize to view them on a public blockchain.

Web3 has the potential to "flip the script" for marketers. Instead of collecting email addresses and hoping to tag users with some form of digital ID, a potential customer could enter your funnel by allowing you to know their identity via their SSI. This would allow you (the marketer) to follow the customer's digital wallet and have access to the data the individual wanted you to have about them. With this subtle shift, it now becomes possible for you to create a system where both you (the marketer) and the user (potential customer) can both share in the value you create.

3   Data

i Batch and Streaming

Speaking of data, your future fan experience will turn two types of data into action:

Fans participating in your future fan experience will generate and use both batch data and streaming data. Batch data refers to data that have been aggregated and stored. If you are working on a spreadsheet and you import a file of sales data, you are processing batch data.

Batch is different from streaming data, which is a continuous flow of data generated by various devices and sensors. Most of us don't process streaming data, but we certainly benefit from apps that do. Social media, dynamic ecommerce sites, video games, and self-driving cars all process streaming data to craft our "real-time" experiences.

No matter what you put on your list of future fan experiences, it will be created by combining batch data and streaming data in near real time.

ii Edge Computing and Cloud Computing

Just as the words imply, cloud computing takes place in a data center that is remote to your users, and edge computing takes place as close to the end user as possible. Both of these computing (and storage solutions) are combined with local storage and computing (smartphone, laptop, chip in some device) to create a complete user experience. By 2025, Gartner predicts that three-quarters of enterprise-generated data will be created and processed at the edge, which is up from just 10% in 2018 (Overby, 2020).

To fully realize the experiences you've imagined, you are going to need software that aggregates and processes batch and streaming data from multiple sources and multiple locations in near-real time. The need for effective hardware and software solutions is vital, given the sheer number of devices connecting to the internet. According to the Telecommunications Industry Association, more than 29 billion devices are connected to the global network, with more than 18 billion Internet of Things devices (Hasan, 2022).

iii Intelligence Layer

When I imagine the fan experience of the future, I think about recognizing anonymous self-sovereign identities that are passing through various data-rich environments and serving them relevant content. I think of a kind of universal cookie (for lack of a better term) that anonymously speaks to the various sensors or event listeners triggering a customized data feed that provides everything from augmented to virtual reality experiences.

This might be accomplished by building an intelligence layer into the system used to converge the available wireless networks. Such an intelligence layer (at the network level) would enable various vendors to bid for experiences the way programmatic advertising systems bid for ad space. Or it might just handle permission levels for various fan experiences. Of course, no such trusted intelligence layer currently exists.

That said, there are various APIs such as Google's new API for geospatial experiences (Sidhu, 2022), that are available to assist in the creation of VR and AR experiences.

4   What's Next?

This list of required technologies is incomplete, but I hope it helps you begin to architect the future you want to live in.

While no one can predict the future, we can set goals and create workflows and processes that may help us get there. One clear path is cooperation and partnering.

You can never have enough engineers, inventors, or creatives on staff. You'll have to partner.

There is so much to be excited about. For example, this generation will have the opportunity to harness the power of AI in ways that previous generations could not. Creating human/machine partnerships with AI coworkers is going to amplify the power of your imagination the same way that power tools amplified the power of our muscles and allowed us to build the modern world.

What's next? That's truly up to you.

References

Andre, L. (2023). *5G statistics you must read: 2023 Adoption Analysis and Data.* Financeson-line.com. Retrieved April 20, 2023, from https://financesonline.com/5g-statistics/

Bass, C. (2023). *How to leverage SSO for better data collection.* HubSpot Blog. Retrieved April 20, 2023, from https://blog.hubspot.com/website/sso

Gough, C. (2022). *Share of sports fans who have experienced emerging technologies outside the stadium worldwide as of December 2019.* Statista. Retrieved April 20, 2023, from https://www.statista.com/statistics/1100546/sports-outside-stadium-experience-technology/

Hasan, M. (2022). *State of IOT 2022: Number of connected IOT devices growing 18% to 14.4 billion globally.* IoT Analytics. https://iot-analytics.com/number-connected-iot-devices/

Kapustka, P. (2022). *Super Wi-Fi usage at SOFI stadium: Sign of a new surge in fan connectivity.* Stadium Tech Report. Retrieved April 20, 2023, from https://stadiumtechreport.com/feature/super-wi-fi-usage-at-sofi-stadium-sign-of-a-new-surge-in-fan-connectivity/

Overby, S. (2020). *Edge computing by the numbers: 9 compelling stats.* The Enterprisers Project. Retrieved April 20, 2023, from https://enterprisersproject.com/article/2020/4/edge-computing-9-compelling-stats

Rahnama, H., & Pentland, A. S. (2022). *The new rules of Data Privacy.* Harvard Business Review. Retrieved April 20, 2023, from https://hbr.org/2022/02/the-new-rules-of-data-privacy

Riojas, J. (2022). *What's the future of data privacy?* Rackspace Technology. Retrieved April 20, 2023, from https://www.rackspace.com/solve/future-data-privacy#:~:text=The%20rise%20of%20data%20privacy%20regulations&text=By%202023%2C%2065%25%20of%20the,%20same%20protection%20in%202010

Sarraf, A. (2022). *Introducing passkeys in chrome.* Chromium Blog. Retrieved April 20, 2023, from https://blog.chromium.org/2022/12/introducing-passkeys-in-chrome.html

Sidhu, B. (2022). *Make the world your canvas with the arcore geospatial API.* Google Developers Blog. Retrieved April 20, 2023, from https://developers.googleblog.com/2022/05/Make-the-world-your-canvas-ARCore-Geospatial-API.html

Statista Research Department. (2022). *Opinions on the preferred use of VR to view sport.* Statista. https://www.statista.com/statistics/1137275/distribution-of-opinions-on-the-preferred-use-of-vr-to-observe-major-sporting-events/

Shelly Palmer is the Professor of Advanced Media in Residence at Syracuse University's S.I. Newhouse School of Public Communications and CEO of The Palmer Group, a consulting practice that helps Fortune 500 companies with technology, media, and marketing. Among his sports clients are the NHL, NFL, LPGA, and Bundesliga, as well as many individual teams. Named LinkedIn's "Top Voice in Technology," he covers tech and business for Good Day New York, is a regular commentator on CNN, and writes a popular daily business blog. He's a bestselling author, and the creator of the popular, free online course, Generative AI for Execs. Follow @shellypalmer or visit shellypalmer.com.

Outlook

Impossible Sports

Brian Subirana and Jordi Laguarte Soler

Abstract

To illustrate how future technologies will shape future sports, Subirana and Laguarte 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 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.

B. Subirana (✉)
MIT Auto-ID lab, Massachusetts Institute of Technology, Cambridge, MA, USA
e-mail: subirana@mit.edu

J. Laguarte Soler
MIT Auto-ID Laboratory, Cambridge, MA, USA

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 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

Table 1 Summary of technologies with their corresponding sport and impact industry

Domain	Technology	Sport	Description	Industry
Life	Artificial life	Al 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	Al 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

watchful eye on him (Golbeck & 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.

Fig. 2 ©Brian Subirana. All rights reserved

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 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

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.
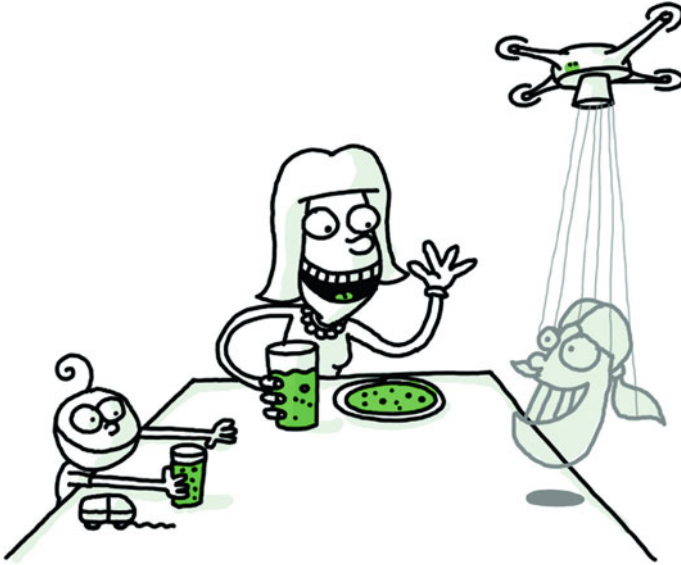
6   2–2:45 PM: Processing—Mental Sports

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. 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).

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

Fig. 5   ©Brian Subirana. All rights reserved

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).
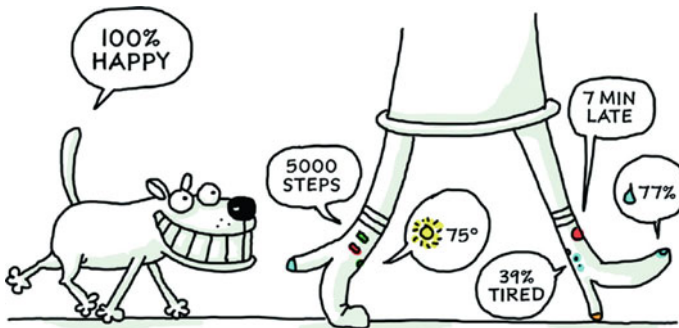
Fig. 6   ©Brian Subirana. All rights reserved

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.

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 Smart Cook 2029, 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.

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

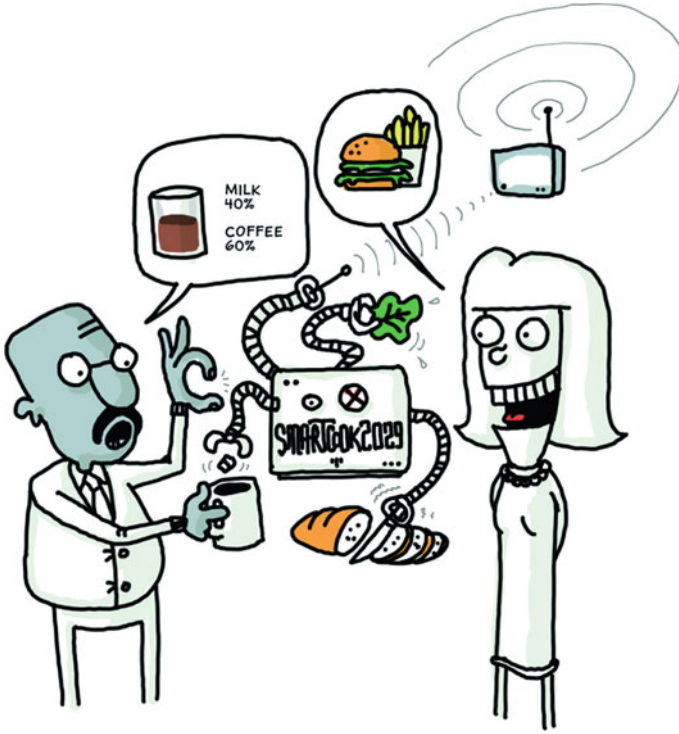**Fig. 7** ©Brian Subirana. All rights reserved

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).

Fig. 8 ©Brian Subirana. All rights reserved

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.

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.

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.

Fig. 9 ©Brian Subirana. All rights reserved

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).

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 & 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
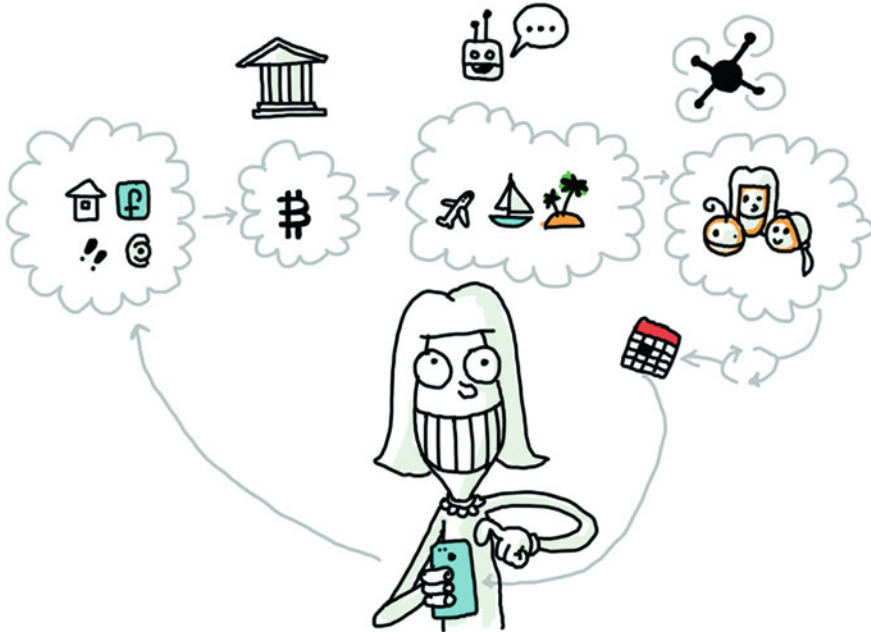
self-driving car for an express journey to her game. As she lies down, Dr. Brown is pleased to learn that her family has overtaken their closest friends in overall exercise and activity rates.

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.

References

Adelantado, F., Vilajosana, X., Tuset-Peiro, P., Martinez, B., Melia-Segui, J., & Watteyne, T. (2017). Understanding the limits of LoRaWAN. *IEEE Communications Magazine, 55*(9), 34–40.

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. *Computer Graphics and Applications, IEEE, 21*(6), 34–47.

Bajura, M., Fuchs, H., & Ohbuchi, R. (1992). Merging virtual objects with the real world: Seeing ultrasound imagery within the patient. *ACM SIGGRAPH Computer Graphics, 26*(2), 203–210. ACM.

Baum, S. D., Goertzel, B., & Goertzel, T. G. (2011). How long until human-level AI? Results from an expert assessment. *Technological Forecasting and Social Change, 78*(1), 185–195.

Golbeck, J., & Neustaedter, C. (2012). Pet video chat: Monitoring and interacting with dogs over distance. In *Proceedings of the CHI EA'12* (pp. 211–220). ACM Press.

Konstantas. (2007). An overview of wearable and implantable medical sensors. In *IMIA Yearbook of Medical Informatics 2007* (Vol. 46, pp. 66–69). Schattauer Publishers.

Mancini, C., Lawson, S., & Juhlin. (2017). Animal-computer interaction: The emergence of a discipline. *International Journal of Human-Computer Studies, 98*, 129–134.

McArthur, D., Lewis, M., & Bishary. (2005). The roles of artificial intelligence in education: Current progress and future prospects. *Journal of Educational Technology, 1*(4), 42–80.

Subirana, B., & Bain, M. (2006). Legal programming. *Communications of the ACM, 49*(9), 57–62.

Subirana, B., Eckes, C. C., Herman, G., Sarma, S., & Barrett, M. I. (2003). *Measuring the impact of information technology on value and productivity using a process-based approach: The case for RFID technologies.* MIT Sloan Working Paper No. 4450-03.

Xiong, X., et al. (2015). Low power wide area machine-to-machine networks: Key techniques and prototype. *IEEE Communications Magazine, 53*(9), 64–71.

Brian Subirana is the Director of the MIT Auto-ID lab, and currently teaches at Harvard University and at the MIT Bootcamps. His research centers on fundamental advances at the cross section of the internet of things and artificial intelligence focusing on use-inspired applications in industries such as sports, retail, health, manufacturing and education. He wants to contribute to a world were spaces can have their own "brain" with which humans can converse. Before becoming an academic, he worked at the Boston Consulting Group and founded three start-ups.

Jordi Laguarte Soler 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 take a long-term perspective on the impact of technology on sports from the viewpoints of athletes, consumers, and managers. Drawing on predictions from experts in this second edition of *21st Century Sports: How Technologies Will Change Sports in the Digital Age* and their own research, the authors paint a picture of what the future of sports will be like in the next three decades. They even venture beyond the thirty-year mark, providing a glimpse of what may come and some direction for navigating the unknown.

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 blockchain or its associated technologies, artificial intelligence, or web3, 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

S. L. Schmidt (✉)
Center for Sports and Management, WHU – Otto Beisheim School of Management, Dusseldorf, Germany
e-mail: sascha.schmidt@whu.edu

K. Stoneham
London, UK

and analyze the effects of technologically induced change processes in sports with the goal of providing some direction through our authors' predictions.

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 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.

Managing data will likely require reliance on blockchain technology, which with its myriad of positives is not without its negatives. Chief among them for athletes, as outlined in the chapter by Potts et al., "are the privacy and security of their personal information" (in Sect. 3). Beyond its management, capturing the full economic value of data will be the mission of managers in the future.

What the full consequences will be for athletes, consumers, and managers in sports 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 a 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), and endless scenario runs using digital twins (Chase in Sect. 3). Training against "virtual ghosts" or against human form-factor robots trained to play like competitors might also be possible in the 2040 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 that athletes in 2030 will eat 3D-printed food (Sect. 2).

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. According to Raveh (in Sect. 5), web3 technology, in particular, will give "athletes greater control over their brand and allow them to receive a greater share of the value they create." 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 won't take long until medics instantly detect athletes' injuries (Siegel & Morris in Sect. 2). Major advances in personalized regenerative medicine will likely appear in the 2040s 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 athletes—those assisted by technology—are 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

Very soon, humanoid robots will serve as sparring partners for humans in sports—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 in a so-called mixed competition.

1.1.4 Mental Athletes

We already observed 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 (Flegr & Schmidt, 2021). Now, facilitated by web3 technologies, mental athletes are supported to compete and engage in virtual worlds and economies; Potts et al. suggest that as the technologies develop, these mental athletes will be supported to compete both mentally *and* physically in these virtual worlds (in Sect. 3).

Mental athletes have a different skill set from 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. In his chapter, Palmer suggests that sports experiences of the future will only succeed if they put the fan (consumer) first (Sect. 5). We confidently predict that the power of consumers will grow. Whatever the consumer wants to see in the future will determine what kind of professional sports are played and how they're presented. Raveh also shares similar views and highlights the importance of GenAlpha consumers—those born after 2010. He suggests that utilizing technologies to create engaging and personalized experiences will be crucial in capturing the attention of these digital natives (Sect. 5). Meanwhile, Schreyer takes us on a journey into the future of European football, where technology like augmented and virtual reality could potentially change the way fans experience the game in 2040. He has ten incredible projections for the future, one of which suggests that the European football spectator may not be as significant. However, even if stadium attendance declines, the consumer will likely play an even greater role in shaping the outcome of some sporting events in the future.

Bellwether for this development are initiatives like the Fan-Controlled Football League (FCFL),[1] where the fans are fully in charge. In this league, fans have complete control, making decisions through blockchain technology for everything from team branding to real-time game choices. Through an interactive video overlay on Twitch, fans can even call plays in real-time, with their choices sent directly to the quarterback on the field. The FCFL also lets fans act as general managers, choosing team names, logos, coaches, and players through a fan-run draft. To make all of this happen, the FCFL uses a new cryptocurrency called the FAN Token, which ranks the voting power of fans. By adding elements from fantasy and video games to traditional sports leagues, teams engage fans of all ages (Schmidt & Flegr, 2023).

In the near future, with the growing demand for bottom-up decision-making, as seen in the emergence of decentralized autonomous organizations (DAOs), fans will be able to invest in their favorite sports teams and potentially benefit from their sportive and commercial success (e.g., transfer fees, prize money, media rights money). Although giving fans more power might seem like a risky move, it can actually lead to better decisions that benefit everyone involved.

---

[1] See www.fcfl.io.

In the distant future, it is conceivable for fans 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 sports consumer to get closer to or even in 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). Schreyer, however, disagrees; instead, he predicts that widespread adoption of these technologies will only contribute to the decline of stadium attendance and, perhaps, the importance of the (European football) spectator (in Sect. 4).

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 et al., ten percent of sports footwear will be fabricated in this manner by 2030 (in Sect. 2). 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 also 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 a greater ability to handle data and technologies in their organizations (Merten et al., 2023). In his chapter, Tobaccowala suggests that sports companies in the so-called third connected age "will increasingly run like technology companies" (Sect. 5). 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).

In the future, we can expect to see more technologies converging to create a new entertainment ecosystem where sports, music, film, art, and education are all interconnected (Sect. 5). This will provide new and exciting opportunities that we may not have even imagined yet, especially in virtual meta-worlds. As a result, it will be crucial for sports leaders to bring together and manage a portfolio of sports and related businesses to create synergies and manage risks in an ever-changing environment (Führer et al., 2021; Holzmayer & Schmidt, 2020a, 2020b). By doing so, they can build sustainable competitive advantages and stay ahead of the game.

Beyond the athlete, team and business portfolio 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 methods that will undoubtedly 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, 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 sportstech 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 authors—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, like Schmidt, Beiderbeck, and von der Gracht (in Sect. 1), we are not concerned with the accuracy of the future images of sport we paint, but with
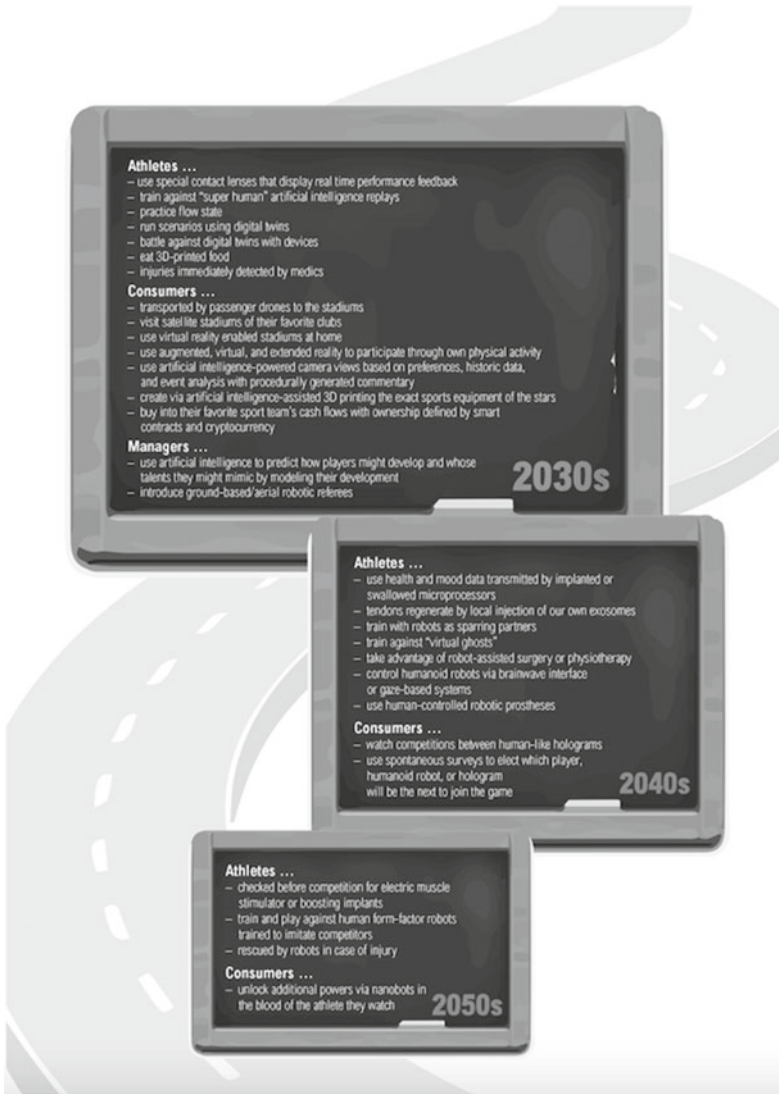
2030s

Athletes …
– use special contact lenses that display real time performance feedback
– train against "super human" artificial intelligence replays
– practice flow state
– run scenarios using digital twins
– battle against digital twins with devices
– eat 3D-printed food
– injuries immediately detected by medics

Consumers …
– transported by passenger drones to the stadiums
– visit satellite stadiums of their favorite clubs
– use virtual reality enabled stadiums at home
– use augmented, virtual, and extended reality to participate through own physical activity
– use artificial intelligence-powered camera views based on preferences, historic data, and event analysis with procedurally generated commentary
– create via artificial intelligence-assisted 3D printing the exact sports equipment of the stars
– buy into their favorite sport team's cash flows with ownership defined by smart contracts and cryptocurrency

Managers …
– use artificial intelligence to predict how players might develop and whose talents they might mimic by modeling their development
– introduce ground-based/aerial robotic referees

2040s

Athletes …
– use health and mood data transmitted by implanted or swallowed microprocessors
– tendons regenerate by local injection of our own exosomes
– train with robots as sparring partners
– train against "virtual ghosts"
– take advantage of robot-assisted surgery or physiotherapy
– control humanoid robots via brainwave interface or gaze-based systems
– use human-controlled robotic prostheses

Consumers …
– watch competitions between human-like holograms
– use spontaneous surveys to elect which player, humanoid robot, or hologram will be the next to join the game

2050s

Athletes …
– checked before competition for electric muscle stimulator or boosting implants
– train and play against human form-factor robots trained to imitate competitors
– rescued by robots in case of injury

Consumers …
– unlock additional powers via nanobots in the blood of the athlete they watch

Fig. 1 Technology impact by decade

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 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!

References

Brynjolfsson, E., & McAfee, A. (2014). *The second machine age: work, progress, and prosperity in a time of brilliant technologies.* W.W. Norton & Company.

Flegr, S., & Schmidt, S. L. (2021). Strategic management in esports–a systematic review of the literature. *Sport Management Review, 25*(4), 631–655.

Fühner, J., Schmidt, S. L., & Schreyer, D. (2021). Are diversified football clubs better prepared for a crisis? First empirical evidence from the stock market. *European Sports Management Quarterly, 21*(3), 350–373.

Holzmayer, F., & Schmidt, S. L. (2020a). Dynamic managerial capabilities, firm resources, and related business diversification–evidence from the English Premier League. *Journal of Business Research, 117*(3), 132–243.

Holzmayer, F., & Schmidt, S. L. (2020b). Financial performance and corporate diversification strategies in professional football–evidence from the English Premier League. *Sport, Business and Management: An International Journal, 10*(3), 291–315.

Merten, S., Schmidt, S. L., & Winand, M. (2023). Organisational capabilities for successful digital transformation: a global analysis of national football associations in the digital age. *Journal of Strategy and Management, 16* (in print)

Opaschowski, H. W. (2013). *Deutschland 2030.* Gütersloher Verlagshaus.

Schmidt, S. L., & Flegr, S. (2023). Lessons on customer engagement from fan controlled football. [Online]. Available: https://hbr.org/2023/03/lessons-on-customer-engagement-from-fan-controlled-football. Retrieved 03 May, 2023.

Smalley, R. (2003). Nanotechnology. Drexler and Smalley make the case for and against 'molecular assemblers'. [Online]. Available: https://pubsapp.acs.org/cen/coverstory/8148/8148counterpoint.html. Retrieved April 07, 2020.

Sascha L. Schmidt is Director of the Center for Sports and Management and Professor of Sports and Management at WHU—Otto Beisheim School of Management in Dusseldorf. In addition, he is a lecturer at the Massachusetts Institute of Technology (MIT) Sports Entrepreneurship Bootcamp, a member of the Digital Initiative at Harvard Business School (HBS), and co-author of various sports-related HBS case studies. 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 the second edition of 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.

Katsume Stoneham works in charity communications and marketing and has an eponymous writing and editing business. She previously worked in public health in a variety of capacities including informatics and infectious disease research. In her free time, she plays football, runs occasional races, and chases after a tiny human.