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

S. L. Schmidt (ed.), *21st Century Sports*, Future of Business and Finance,
https://doi.org/10.1007/978-3-031-38981-8_7

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).

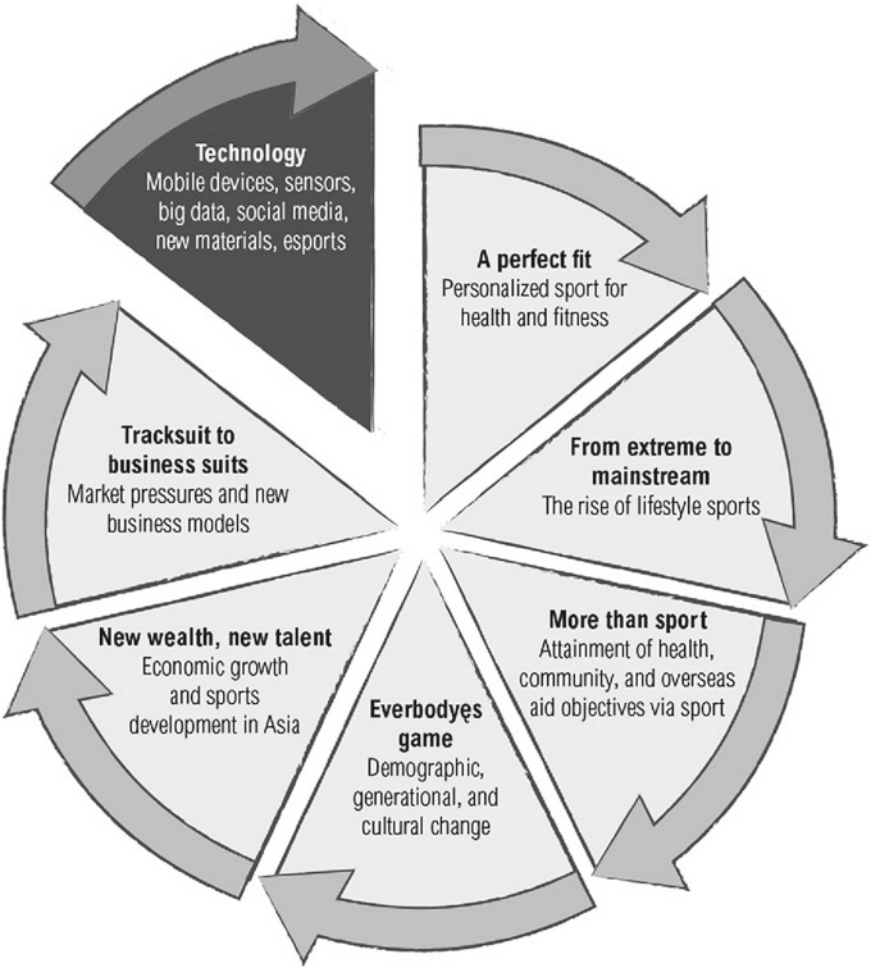

Fig. 1 Megatrends and key drivers in the future of sport. Adopted and amended from Hajkowicz et al. (2013)

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

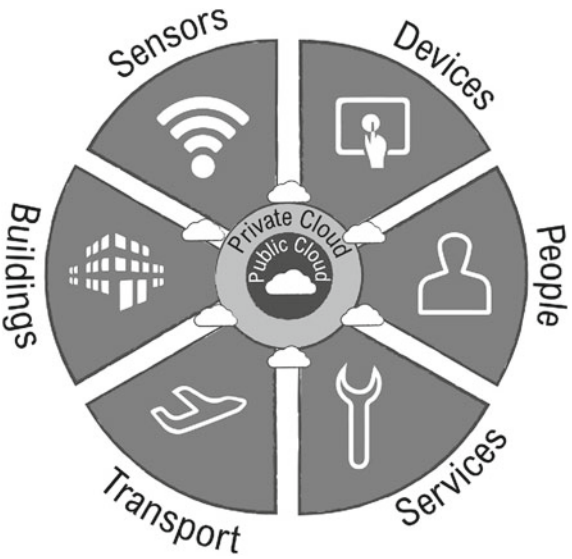

Fig. 2 The internet of things: Networking people, objects and services

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

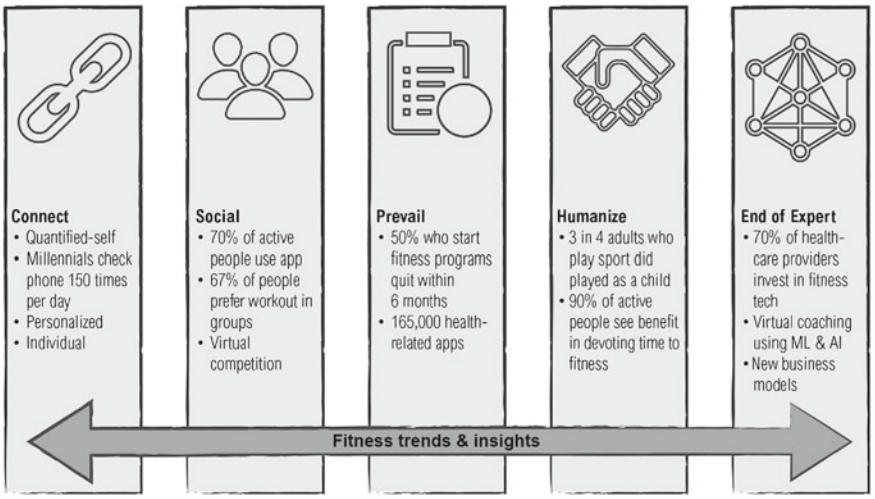

Fig. 3 Insights from fitness survey and resulting trends

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

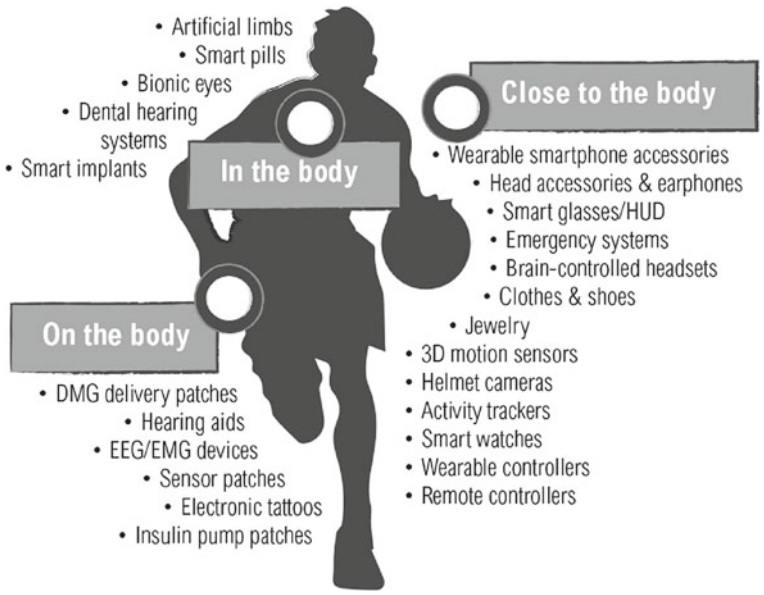

Fig. 4 Location of athlete sensors and devices. Adopted from Stammel (2015)

("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-

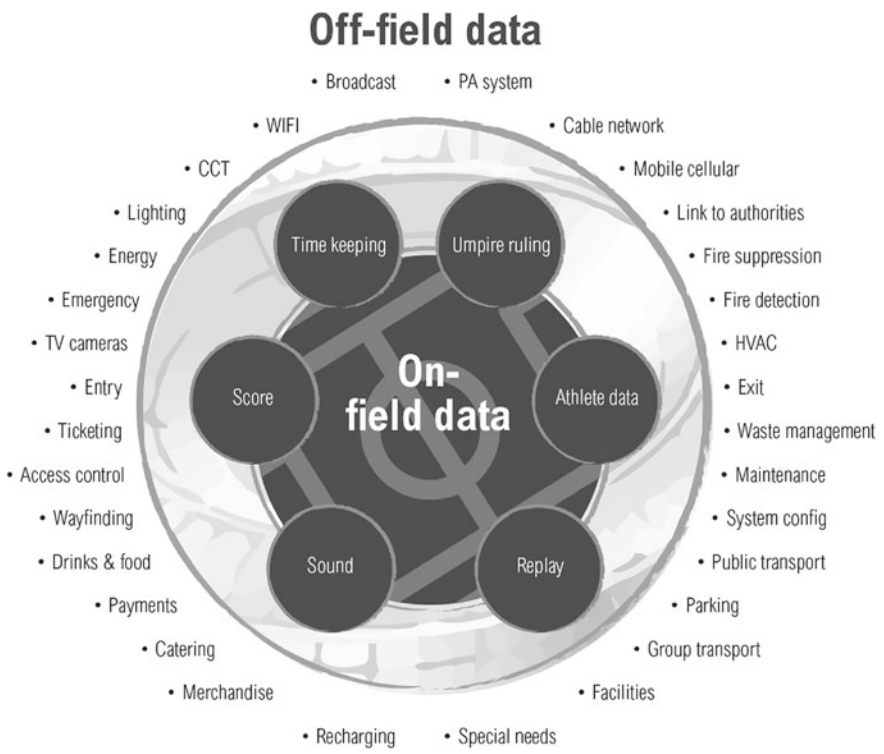

Fig. 5 Digital stadium platform

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-broadcasting-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).

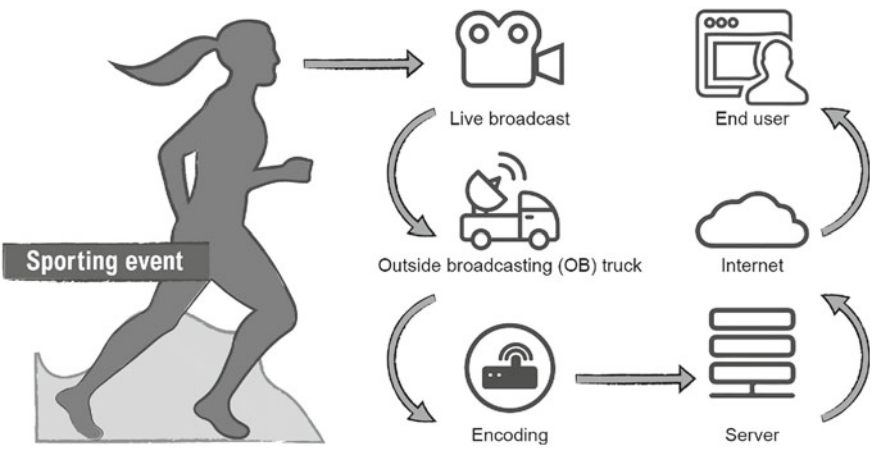

Fig. 6 Over-the-top (OTT) carrier streaming setup resulting in high latency

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.

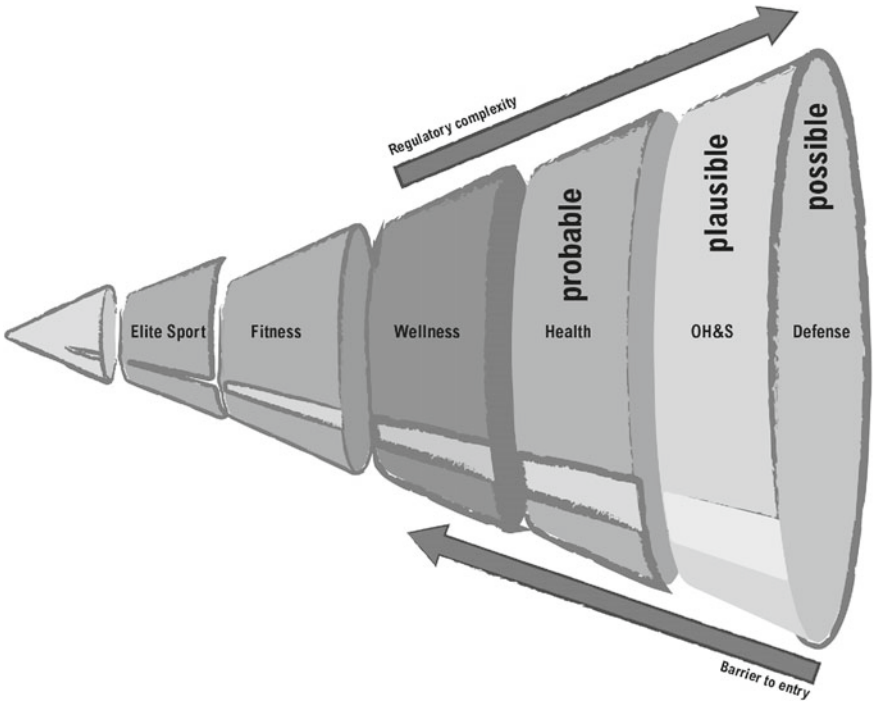

Fig. 7 Technology translation from sport to health, OH&S, and defense

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.

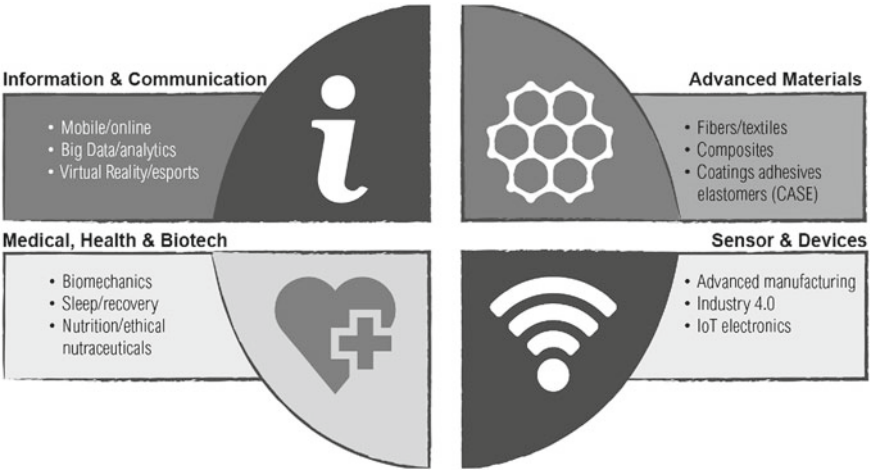

Fig. 8 Areas and aspects of sports technology

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.