SUSTAINABLE, INCLUSIVE, INNOVATIVE: THE ROLE OF ENGINEERING IN SPORT.

Institution of MECHANICAL ENGINEERS

Improving the world through engineering

“”

The UK is a leader in the field of sports engineering, and with more support this could grow into an exciting network of home-grown startups to help boost the economy.

Dr Thomas Allen CEng FIMechE

“”

Sport plays such an important role in society and its future will be shaped by the issues of sustainability, inclusivity, and innovation.

Carly Nettleford EngTech MIMechE

Authors

Dr Thomas Allen CEng FIMechE
Reader in Mechanical Engineering
Manchester Metropolitan University

Carly Nettleford EngTech MIMechE
Engineering Policy Advisor
Institution of Mechanical Engineers

Matt Rooney CEng MIMechE (editor)
Head of Policy
Institution of Mechanical Engineers

Acknowledgements

Jamie Capel-Davies, of the International Tennis Federation, for meeting to discuss topics related to the report.

For more information contact
the IMechE policy team:
policy@imeche.org

Published October 2023
Design: Karoshi

Reviewers

Johsan Billingham
FIFA

Dr Anna Coppel CEng MIMechE
Arup

Eric DeGolier
Body Rocket

Dr Olly Duncan
Manchester Metropolitan University

Dr Marcus Dunn
Heriot-Watt University

Prof. Steph Forrester
Loughborough University

Emelia Funnell
IDA Sports

Dr Rebecca Grant
Loughborough University

Prof. Steve Haake
Sheffield Hallam University

Dr Adil Imam
Canterbury Christ Church University

Prof. David James
CEO Labosport Group

Olga Kravchenko
RHEON Labs and Imperial College

Dr Katrine Okholm Kryger
St Mary’s University and FIFA

Dr Aimee Mears
Loughborough University

Dr Jonathan Shepherd
PING

Contents

Executive summary

The UK is a leader in the field of sports engineering, but more could be done to capitalise on the many comparative advantages the country has. By increasing support for research and development, more innovative start-ups could be created, and they could grow faster. Establishing sports engineering hubs would also encourage large multinational companies to locate research and development facilities here.

The UK is home to world-renowned sports teams, athletes, and competitions. This brings many economic and social benefits and means that huge resources are put towards developing sporting technologies for elite athletes. The various sports engineering institutions should work together to ensure that innovations developed for elite athletes filter into grassroots sport. Similarly, governing bodies that primarily regulate elite sporting competitions can and should encourage the whole industry to be more sustainable and inclusive.

The increased use of data to improve the performance of professional athletes has been a major trend in the last decade and will likely accelerate with the use of artificial intelligence. To make the most of this development, organisations that collect such data should work together to standardise it and encourage making it freely availably. To ensure that sporting goods are designed for everyone, researchers should be trained from undergraduate level onwards to follow an inclusive design approach and include a diverse range of participants in their studies.

Finally, to promote continued UK leadership in sports engineering research and to support underserved groups in entering the field, a culture of open innovation and collaboration should be fostered.

The report Sustainable, Inclusive, Innovative: The Role for Engineering in Sport makes the following headline recommendations:

1. Increased investment in facilities for research related to mechanical testing of sporting goods and testing technology in sporting scenarios.
2. More funding for schemes to transfer technologies developed for elite sport into the community for wider societal benefit.
3. Encouragement of sports technology providers by governing bodies to embrace independently audited ecolabels that will help transition to more sustainable materials and manufacturing.
4. Encouragement of open-access, standardised data as the norm in the field of sports engineering.
5. A UK sports engineering network to support transdisciplinary collaborations needs to be established.

More context and rationale for these recommendations are given in later sections of the report.


28
argentina
322

Report scope and definitions

Definition of terms in the context of this report

1. Sport	Competitive and non-competitive activities involving physical exertion and skill, including recreational activities like snow-sports, roller-sports, cycling, and jogging.
2. Athlete	A person engaging in sport of any level or ability. The word elite is added when specifically referring to athletes who compete at the highest level.
3. Sports Engineering	The research, design and development of sports equipment, aids and measurement systems. The term is used to capture the transdisciplinary field of sports engineering and technology. The field is considered to encompass related disciplines, such as sports biomechanics and sports physics.
4. Sporting goods	Products used for sport, namely equipment, protective devices, clothing, footwear, running blades, wheelchairs, and wearable sensors.
5. Sporting facilities	Venues where sports training and competition take place, namely pitches, courts, and tracks and trails for activities such as running, cycling, and snow sport. The focus is sporting facilities with which athletes and their equipment contact and interact, not buildings, stadiums, and transport infrastructure.
6. Officiating technologies	Technologies used to assist the decision-making process during competitions, including cameras and tracking systems, sensors (e.g. 'smart football'), and microphones.
7. Regulatory technologies	Technologies, such as mechanical test devices, used in the monitoring and testing of sporting goods and facilities.
8. Training tools	Technologies used to monitor and enhance the performance of athletes, including force plates, camera systems, and wearable sensors.
9. Sporting technologies	Encompassing 4–8 above.

In scope	**Out of scope**
Sporting technologies as defined in the definitions table.	• **5**. in definitions table excludes buildings, stadiums, and transport infrastructure. • Management of sports teams, events, and competitions. • Automotive sports, such as F1 • E-sports • Sports medicine related to surgical interventions

Engineering and sport

Background to the report

Engineers play a vital role in the sports industry by driving technological advancements. In 2012, the Institution of Mechanical Engineers (IMechE) published Sports Engineering: An Unfair Advantage.[1] The report described how engineering contributes to elite sport and the fine balance between embracing technologies that can enhance athlete performance and maintaining fair competition. In the subsequent decade, technological advancements have continued to allow elite athletes to push boundaries and break records. Technological advancements have also helped recreational athletes improve their performance and engage in sport safely. The use of data within sport to inform decision-making has expanded and become increasingly important.

This report describes how the field of sports engineering has developed since 2012. It expands upon its predecessor by showcasing how technology is helping sport become more sustainable and inclusive. Recommendations are made on how the UK can maintain and capitalise on its leading position in the field of sports engineering, and how to make sport more sustainable and inclusive.

The role of engineering in sport

Engineers develop and manufacture sporting technologies, which, in the context of this report, encompass sporting goods and facilities, officiating and regulatory technologies, and training tools. They also undertake research related to sporting technologies, which can underpin standards and regulations that ensure fair competition while improving safety and athlete welfare. Engineers face the challenge of bringing new and innovative sporting goods and facilities to the market, which should ideally meet the needs of as many people as possible while having a minimal impact on the environment.

As engineering techniques and tools develop, so does the design process and the sporting goods and facilities themselves. Such developments in sporting goods and facilities are often incremental, with occasional step changes.[2] Engineers will analyse previous models of a product, collect user feedback, and use their expertise to make improvements using the latest technology. Technological developments have also enhanced manufacturing processes. Lightweight, high-strength sporting goods can be mass produced precisely and reliably with ever-improving manufacturing technologies. The process of sporting goods development is transdisciplinary and follows a path that can include materials engineering, aerodynamics and fluid dynamics, simulation and modelling, mechanics and physics, electronics and sensors, biomechanics and user feedback, and data analytics and machine learning. The rapid uptake sports engineering sector is an ideal place to test and demonstrate new technologies,[3] which can then be applied to other sectors.

The impact that engineering and technology have had on sport over the last decade has been vast and is continually growing. Examples within the report are: 1) advanced materials, 2) digital and artificial intelligence (AI) technologies, 3) officiating and fan engagement technologies, and 4) mechanical testing and engineering analysis.


ROLEX
ROLEX
OFFICIAL
REVIEW

Sports engineering in the UK

The sports industry, including viewing and participating, is one of the UK's largest industries, providing a contribution of ~£40 billion to the UK economy.[4] It is estimated that in 2022, almost 200,000 people were working in the UK sports industry.[5] The UK was nominated as the most influential country for sports technology by the inaugural Sports Technology Annual Review.[6] Indeed, the UK is a world leader in the field of sports engineering. It has academic centres of excellence, located in various universities throughout the country. UK-based researchers collaborate with major sporting goods brands, the best sports teams in the world, and international sporting governing bodies. Working together, these sports engineering institutions are developing new technologies to enhance the sporting spectacle and improve the performance, safety, and welfare of athletes at all levels.


Carbon

Sustainable

While there are various definitions and types of sustainability, including social and economic, this report focuses on environmental sustainability. The specific focus is sporting goods and facilities. Given the many pledges by national governments, including the UK, to reach Net Zero greenhouse gas emissions by mid-century, environmental sustainability is a priority in all industries, including sport.

The sports industry has shown evidence of its commitment to sustainability, but further action is needed.[7] The British Association for Sustainability in Sport provides support to sports clubs, venues, and governing bodies and is focused on building a sustainable future. UK Sport has an environmental sustainability strategy with the goal for high-performance sport to have a net positive impact on the environment by 2040.[8] The strategy highlights actions and targets to be implemented by 2025 and highlights how elite sport influences environmental sustainability.

The implementation of UK Sport's strategy will help raise awareness of the impact of sport on the environment and encourage people to prioritise sustainability moving forward. Governing bodies can also influence the sustainability of their respective sports. For example, Union Cycliste Internationale is introducing requirements for cycling teams to reduce their carbon emissions.[9] From a sports engineering perspective, cycling teams could reduce their use of wind tunnels, including the impact of travelling to them, by focusing more on using computational fluid dynamics (CFD) and field testing for aerodynamic analysis.

Environmental impact of sporting facilities

Sporting facilities are vital to local communities and they help people remain active and healthy, particularly in urban environments. It is also vital to ensure that such societal benefits can be achieved with minimal environmental impact. Indoor facilities can have specific safety and regulatory requirements,[10] particularly swimming pools, ice rinks, and snowdomes. Potentially harmful chemicals can also be required to create and maintain such facilities (e.g. temperature and hygiene). They can also have a large physical footprint and contribute to urbanisation.

Outdoor facilities, such as mountain biking and running trails, and white-water courses on rivers can cause erosion of the natural environment. Outdoor pitches, courts, and courses are often intensively managed, typically involving regular mowing, watering, and the use of pesticides,[11] and their presence can raise temperatures[12] and create monocultures and a lack of biodiversity. The industry are taking action to improve environmental sustainability, such as by introducing independently verified ecolabels and awards for good practice.[13] The use of artificial and hybrid turfs can further reduce biodiversity.[10] A particular concern related to artificial turf is the use of microplastics, and the proposed European Union (EU) legislation means that manufacturers may soon need to seek alternative options.[14] Microplastics can be harmful to the environment, as they often end up in rivers and oceans.[15] Manufacturers, governing bodies, test houses, and academics must continue to work together to develop and implement more environmentally friendly sporting facilities that do not compromise performance and increase injury risk and cost.

Use and disposal of sporting goods

A key part of the sports industry is making and selling sporting goods. There is an environmental impact associated with the production, transportation, sale, and end-of-life disposal of these sporting goods. As they can be difficult to repurpose or recycle, sporting goods regularly end up in landfills, where they slowly break down and become absorbed in the natural environment, often as microplastics. Scope 3 greenhouse gas emissions (i.e. indirect) are typically the largest category for major sporting goods brands[16,17]; therefore, effort must be focused on increasing environmental circularity and reducing end-of-life waste. This is particularly important when services such as manufacturing and transportation of goods are outsourced. The full scale of the environmental impact is hard to gauge, as there is limited publicly available information on the volume of sporting goods being produced and ending their lives as waste. While estimates can be made based on the revenue of the brands marketing the products, transparency and accurate reporting of such data would make it easier to quantify the environmental impact of the industry and implement meaningful sustainability strategies and regulations.

Based on various reports from Statista, the total annual revenue of the global sporting goods market (including equipment, apparel, swimwear, athletic footwear, and fitness/activity-tracking wristwear) likely exceeds £300 billion.[18] The annual turnover of UK sporting goods manufacturers is ~£1 billion, with ~30 of them each exceeding £5 million annually.[19] 85% of UK respondents to the Global Consumer Survey 2021 had bought sporting goods in the last two years, mainly in the form of footwear and clothing.[19] Most of these products were made overseas, with an annual import value to the UK of ~£1.5 billion.[19] These metrics signify a huge volume of sporting goods being produced and transported for sale each year, both globally and in the UK, much of which likely ends its life as waste.

While this trade in sporting goods contributes to the global and UK economy, the sustainability of the way in which the items are made and transported, the material used, and the environmental impact must be considered. Indeed, UN 'Sustainable Development Goal 12' is 'Responsible Consumption and Production'.

While UK-based respondents to the Global Consumer Survey 2021 ranked 'Comfort' and 'Good Fit' as their first and second most important purchasing decisions, 'Sustainability and Eco-Friendliness' was allocated ninth place. A particular concern apparent in the survey results regarding the environmental impact of sporting goods is items with a short lifespan. This short lifespan can be due to items losing appeal, such as 'fast fashion' clothing or footwear or a loss of function and performance due to degradation and wear from use. Almost half a billion pairs of athletic shoes (i.e. specifically designed for sports purposes) are sold globally each year,[20] and running blogs and magazines often suggest that runners replace their shoes every 300 to 500 miles (e.g.[21]). These figures suggest huge volumes of end-of-life waste from running shoes alone. The respondents of the survey ranked 'High Quality' and 'Durability' in third and fourth places, respectively, indicating that UK consumers want well-engineered long-lasting sporting goods. The European Commission plans to end the fast fashion culture and encourage the use of more durable textiles,[15] with implications for sports shoes and clothing.

Factors influencing the sustainability of sporting goods

Key factors influencing the environmental sustainability of sporting goods are the materials used, the production process, and the end-of-life scenario. Regarding materials, sustainability can be improved by using less and using those that are natural, recovered, or recycled. The end-of-life recycling of sporting goods can be made easier by designing them to be disassembled and to have fewer materials and parts.[22] Simplifying products in this way while striving to improve performance could present challenges to sporting goods brands, particularly those that have historically based their marketing campaigns on the use of specialist and complex materials and technologies.

Sporting goods brands often collaborate with specialist technology providers when developing products. Reclaiming and recycling materials at the end of life can be more complex when the products include technologies from multiple providers. New EU legislation implemented to make batteries more sustainable (Regulation 2023/1542)[23] will have broad implications for the development of 'smart' sporting goods, such as heart rate monitors, fitness trackers, and clothing with integrated electronics.

The durability and hence lifespan of sporting goods can be improved by applying advanced engineering to the research and development process. Various studies have investigated how running shoe materials degrade with use, with a view to increasing product lifespan.[24,25,26,27] The environmental impact from the production of sporting goods can be reduced by using less energy or water or both and reducing or reusing waste material, all while avoiding the use of harmful substances.

The source of energy used for power production is also a factor. It is becoming increasingly important in the drive to decarbonise economies to consider the embedded emissions of imported products. Affluent countries, such as the UK/EU, should not simply be outsourcing their emissions. Indeed, the EU has recently implemented a 'Border Carbon Adjustment Mechanism' to ensure that this is accounted for in imported goods.[28] Sporting goods factories are typically large and located in a few countries that have low labour costs. Having factories concentrated in a few places away from many of the consumers can increase the energy cost of transportation.

Some brands engage in the practice of 'carbon offsetting', where the intention is to compensate for environmental impact by investing in activities such as renewable energy or tree-planting schemes. Some of the major sporting goods brands are also investing in 'smart' automated factories located closer to their research and development facilities and many of their customers, a practice sometimes referred to as 'reshoring' or 'greenshoring'. The UK has a thriving sporting goods industry, which could benefit from having such a smart factory or manufacturing plant close to the customer base.

Cycling green initiative

Politicians in the UK have introduced many scheme to encourage cycling. Twenty years ago, the introduction of a congestion charge to drive into London began. In 2010, the Greater London Authority introduced blue painted 'cycle superhighways' that have allowed cyclists to navigate around London while reducing the risk of accidents happening with other vehicles. Beyond London, there are other cities with large cycling populations, including Oxford, Cambridge and York, to name a few. The UK Government has set targets to double cycling in the UK by 2025 in their Transport Decarbonisation Plan and has an ambition to make cycling and walking the natural choices for shorter journeys, or as part of a longer journey, by 2040.[29]

Moving towards sustainable sporting goods

It is now common for sporting goods brands to display their environmental credentials on their websites and market products as environmentally friendly. Such marketing claims are often based on innovations in materials, design, and manufacturing to facilitate sustainable sporting goods. The reliability of such environmental claims is not always obvious to customers, and the EU has plans to ensure that accurate information is presented at the point of sale.[30] Indeed, claims made by brands of environmental benefits should be substantiated and independently audited to prevent 'greenwashing'. Engaging in initiatives that promote independent certification of environmental sustainability claims, such as EU Ecolabels, and having engineers involved in the marketing process, would help ensure accurate evidence is presented to consumers.

Fibre–polymer composites are widely used in sporting goods. These composites have led to many improvements, including lightweight tennis racquets with larger heads[31] and, more recently, curved stiff plates within running shoes that enhance performance.[32] Sporting goods brands are now trialling composites with natural fibres and biobased polymers. Such composites can bring environmental benefits as well as engineering challenges, as they can have inferior and more variable properties than their synthetic counterparts.[31] The challenges involved in recycling composite materials have led to the World Sailing Trust working with other sporting bodies to create the Carbon Fibre Circular Alliance.[33]

The Sports Technology Annual Review[34] notes two examples of sports clothing where innovations in materials and manufacturing techniques are lowering the environmental impact of production: One of these is clothing made with 70% recycled content with a needle-punching process, which is claimed to reduce carbon emissions by ~75% over a traditional knit.[35] The other is a spandex in which bio-based materials (derived from corn) replace 30% of petroleum-based resources as the raw ingredient, with claims of a 20% lower carbon footprint than conventional spandex.[36] Elsewhere, a sporting goods brand has partnered with the environmental organisation Parley for the Oceans to create shoes from waste plastic.[37] Another sporting goods brand has an initiative where customers can return certain shoes and t-shirts so that the materials can be recycled and reused in new products.[38]

Collaboration between the organisations developing sporting goods and those responsible for waste management could facilitate the development of processes for sorting materials and components and returning them to the original developer for reuse and recycling. Many synthetic materials, such as polyester, nylon, and elastane, are oil-derived. Therefore, costs fluctuate with oil prices, providing financial incentive for sporting goods brands to explore natural alternatives. Sporting goods brands must also find alternatives to fluorocarbons, as are traditionally used in outdoor clothing and ski wax. Fluorocarbons are being phased out of use,[39] as they are hard to break down and can contaminate the natural environment.

Sporting goods with a short lifespan

Efforts to reduce the environmental impact of sporting goods should focus on products with short lifespans, due to a loss of appeal or function. Such products can include items like shoes and clothing, bike tyres and brake pads, and balls.

Tennis balls are a well-known example of an item of sporting goods with a short lifespan, with estimates of ~300 million used each year.[40] If those balls were laid side by side in a line, the length would likely exceed the distance from IMechE in London all the way to New Zealand. Most tennis balls are internally pressurised to achieve the required rebound characteristics. The internal pressure of these balls slowly decreases after they are removed from their pressurised packaging, which lowers bounce height. The felt cover on the ball also wears (releasing microplastics) and deteriorates with use, which changes the bounce and flight characteristics.

As such, the tennis balls used in competitions are regularly replaced. Balls are used for no more than nine games at the Wimbledon Championships, resulting in >50,000 being used at the tournament[41] and then passed on for other use. Some companies are researching how to make tennis balls more sustainable by including recycled material. For competition use, such balls would require approval by the governing body. Once a product is approved, the governing body can randomly select samples being sold and test them to check for continued adherence to regulations. The properties of materials typically degrade during the recycling process; hence, the term downcycling is often used. Such degradation could create challenges for companies striving to produce products that consistently adhere to governing body regulations when using recycled materials.

Governing bodies must encourage brands to invest in developing sustainable sporting goods, which could include introducing some form of 'ecolabelling' system. An ecolabel could be an option for approved products that meet certain sustainability requirements, such as the EU Ecolabel initiative. While governing bodies would also likely need to introduce auditing to ensure that the brand adheres to these sustainability requirements, this could be simplified by aligning with established initiatives. In addition to promoting sustainable products, governing bodies such as the ITF can take steps to increase product lifespan, such as lengthening the time between ball changes in competitions.

Such an approach requires collaborative research to determine the wider implications of environmentally motivated rule changes and the necessary steps needed to ensure adequate product performance. This could include investigating the deterioration of tennis ball properties with use, alongside ways to prolong their lifespan. Further research is required to help bring environmentally sustainable products to sport without compromising performance and safety. Such research requires collaboration and transparency between academics, sporting goods brands, test houses, and governing bodies. The goal is ultimately to change consumption habits and move away from the current use and discard culture.[15]

> "The ITF are undertaking research on how best to extend the lifespan of tennis balls, with a view to reduce the environmental impact of the game.
>
> **Jamie Capel-Davies**
> Head of Science & Technical at the ITF

Automated sporting facilities management

A UK-based start-up has designed robots to pave the way for managing sports fields more sustainably. The E-Nano Sprout autonomously roams football pitches, golf courses, and other high-performance grass pitches that require intensive management to provide up-to-date and precise information on field health. The company claims that this minimises injury risk, reduces the use of water, agrochemicals, and energy, and enables precision for performance.[42]

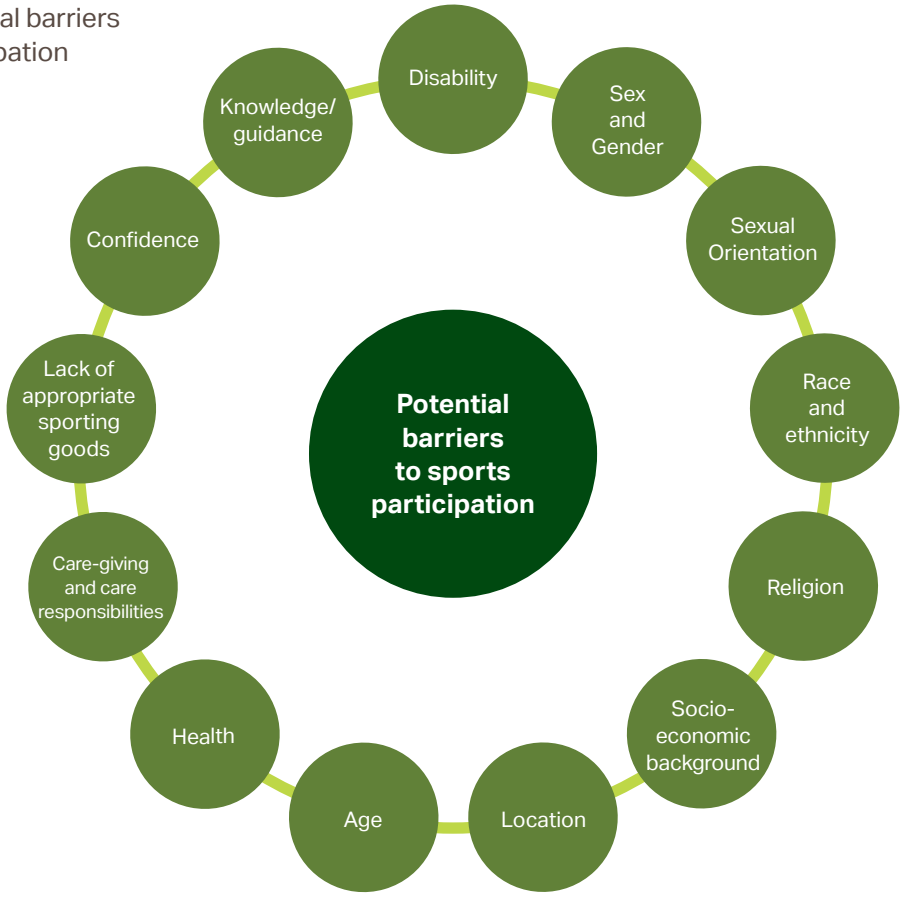
Inclusive

It may seem obvious that sport is becoming more inclusive. Elite competitions such as the Paralympics increasingly receive coverage on national TV. Lottery/UK Sport funding means that UK Paralympians receive more support than those of many other nations. Interest in women's sport is also increasing. For example, women's football has risen in prominence, further elevated in England by investments in the game from the Football Association and the success of the 'Lionesses' in the UEFA Women's Euros in 2022, then closely followed by second place at the 2023 FIFA Women's World Cup. However, a focus on these competitions for professional athletes may not tell the whole story.

There are many aspects to inclusivity and potential barriers to participation (see **Figure 1**) beyond sex and disability. Participation in certain sports may be beyond reach if you do not have access to certain facilities or come from a lower socioeconomic background. Where you live may determine what activities are available. Culture or religion, such as clothing requirements and gender expectations, could be another determinant. The Title IX bill[43] ensures that women in the USA have the same access to sport as men and has helped bring them success in the Olympics. In 2015, Sport England established the This Girl Can campaign[44] to change perceptions of women's sport and get more people active.

This section examines how technology has enabled or could widen participation in sport at all levels. This is a broad topic and could include things such as infrastructure and transport, but this report focuses on the sporting goods and facilities with which athletes interact.

Figure 1: Potential barriers to sports participation



Sports technologies for disabled athletes

Technological developments have allowed disabled people to participate in more sports. Innovations in prosthetics, assistive technology, and wheelchair design have been transformative. A key trend has been towards more bespoke sporting goods. A well-known example of engineering assisting disabled athletes is blade-style prostheses. When designing these blades, the type of sport for which they are being used must be considered. For example, when comparing their use in cycling versus track and field events, the engineer has different factors to consider, as cyclists perform a different type of motion at a higher speed. Aerodynamic drag is the largest resistive force acting on cyclists when they travel at high speeds. As such, engineering efforts are often focused on minimising the aerodynamic drag of racing cyclists and their equipment.[47] Within the restraints of governing body regulations, sports engineers working with disabled athletes can, for example, design prosthetics in aerodynamic shapes to reduce drag while maintaining performance.

Wheelchair technology for elite athletes has become increasingly advanced and is now designed for specific sports and user requirements. For example, modern basketball wheelchairs have customised bucket seats and higher backrests to provide better stability to players. These wheelchairs have features that allow players to lean further back to take shots and can be adjusted to different athlete needs and abilities. Badminton wheelchairs also have higher backrests and extra caster wheels at the rear, providing higher mobility and allowing athletes to twist or lean backwards steadily. As sporting goods for disabled athletes become increasingly specialised, it is important to ensure that these are widely available and accessible for all, not just the elite.

The Paralympic Games

The Paralympic Games have grown in prominence, with more athletes competing each year. The Tokyo 1964 Paralympic Games had under 400 athletes from 21 countries competing, around a fifth of whom were women. In 2021, the Tokyo Games had over 4,500 athletes from 163 countries competing, around two-fifths of which were women.[45] The International Paralympic Committee continually strives to be more inclusive, and there are now many disability groups at the Paralympics.[46]

Various organisations support disabled people of all athletic abilities to participate in sport. For example, Paralympics GB and Toyota established the Every Body Moves initiative,[48] which aims to encourage and highlight inclusive activities that non-disabled and disabled people can do together. They provide links to local activities and showcase stories of individuals who may have struggled in the past but have changed their lives through sport. They also provide links to various clubs and organisations that welcome and encourage disabled people to take part, including wheelchair rugby, fencing, curling, and much more. Sport for Confidence focuses on improving the well-being of disabled people who have been marginalised. They use a team of occupational therapists to provide expertise to those who need extra support and encouragement to become more active. Other organisations that provide similar activity include Mencap, Cerebral Palsy Sport, and Foundation of Light.

Activity Alliance provides training to companies to show them how to become more inclusive and offer programmes, enabling organisations to support disabled people to be and stay active. Their research found that 77% of disabled people would like to be more active, yet only 20% had taken part in an organised activity session last year. They provide information and locations of inclusive gyms and programmes that can be completed safely at home.

Their recommendations include the following:

- Welcoming approaches to greater accessibility and adaptability, including at price points – using engineering to innovate and adapt rather than recreate.
- Working with disabled people in sport to focus on needs, specifically using coproduction or codesign to help design equipment or get input on accessibility.
- Investing in the sector to encourage disabled people to join the engineering field to have more representation and lived experience in developing design.

Disabled people rely on well-engineered assistive technology to participate in sport, which is often bespoke or customised to their specific needs.[49] If more disabled people start engaging in sport from a broader and more diverse population, it is likely that new design challenges and opportunities for assistive technologies will arise. As such, there is a need to fund transdisciplinary research into how best to develop accessible low-cost assistive technologies to help a broad and diverse population of disabled people engage in sport safely.

Invictus Games

The Warrior Games were founded in the USA to enhance the recovery and rehabilitation of wounded, ill, and injured service members and to provide them with exposure to adaptive sports. The creation of the Invictus Games in London by Prince Harry followed four years later in 2014. The Invictus Games aims to harness the power of sport to support rehabilitation and generate a wider understanding and respect for those who serve their country. The last Invictus Games were held in Dusseldorf in September 2023, bringing together over 500 competitors from 20 nations. The next one is Vancouver-Whistler 2025, which will include winter sports.[50]

Inclusive sports technology

Sports technologies should ideally work well and fit the needs of as many people as possible, regardless of factors such as sex, gender, race and ethnicity. Despite this need, sporting goods brands tend to generalise their products to their main customer base to reduce costs and make it easier to manage their stock. Sporting goods targeted at women often appear to just be scaled-down versions of those offered to men and branded in pink or another stereotypical feminine colour.[51] One example is mountain bikes, where offerings for women are often the same as those designed for men but with adjusted size ranges. In some sports, with growing awareness and campaigns around the specific needs of women athletes,[52] this trend is beginning to change.

The prominence of knee injuries among professional women footballers in 2022 sparked various investigations into why this was happening. Studies have shown that women are more likely to suffer knee injuries from sports participation than men.[53,54] It is unclear why this is the case, and it is likely multifactorial, but equipment that has not been designed specifically for women and poorly maintained playing surfaces may be part of the problem.[52] The tendency to design sporting goods for men could be putting women at a higher risk of injury, and further research on this topic is needed.

As is often the case with sports footwear, football boots have historically been designed for an average-size white man and then simply scaled up or down proportionally. Most women footballers find such boots uncomfortable,[55] and a recent parliamentary enquiry focused on the general lack of women-specific offerings.[56] Designers did not take into consideration that, on average, female feet are shaped differently from those of males. Females also move and run in a different way to males, and yet football boots are designed around male movement and traction requirements. A start-up that was established to address this issue and develop women-specific sports footwear won the 2022 ISPO Brandnew award.[57] In the build-up to the 2023 FIFA Women's World Cup, some of the major sporting goods brands released unisex football boots, with a smaller number releasing designs specifically marketed towards women.

Health and safety in sport

Sporting injury risk can create barriers to participation. Injuries can prevent people from participating in sport during the recovery period, and a subsequent decline in fitness can deter them from resuming participation. There can also be lasting effects from sports injuries, which can limit or prevent further participation, particularly in later life, and bring about health complications. The management of concussion risk from sports participation is a societal concern, as evidenced by a recent parliamentary enquiry[58] and the establishment of the Podium Analytics Institute for Youth Sports Medicine and Technology at the University of Oxford.[59] Media reports, documentaries, and films are all helping to raise public awareness of the concussion risks associated with playing certain sports. According to the Drake Foundation, concerns related to brain health have caused >60% of amateur rugby players to play less or stop playing entirely.[60]

The latest Sports Technology Annual Review[34] notes how wearable sensors are being used to detect head impacts and manage concussion risk in sport. The review highlights two examples of mouthguards fitted with sensors. The sensor technology developer for one of these is Swansea-based and they won the 'Best Technology for Injury Prevention or Rehabilitation' category at the 2020 Sports Technology Awards and is cited in the government's response to the DCMS Select Committee Report on Concussion in Sport.[61] They partnered with a Hemel Hempstead–based brand to implement their sensor system within mouthguards.[62] It is important to demonstrate the validity of wearable sensors before using them,[63] which, in this case, involved comparison against an instrumented headform.[64]

Instrumented mouthguards are now being used in elite sport to help manage concussion risk, including in rugby union.[65] Eye-tracking technology has the potential to identify whether a person is concussed following a head impact. World Rugby is trialling such eye-tracking technologies for this purpose.[66] Such data collected during actual sporting events can inform test methods for protective devices like helmets,[67] potentially leading to better products, lower injury risk, and enhanced player welfare.

Inclusive data

This section explores the role technology can have to widen participation in sport. However, a longstanding problem in the industry and the wider world has been a lack of diversity in the data used in research and development. To ensure sporting goods meet the needs of as many people as possible, the data collection and analysis that underpins technology development must be taken from a wide and diverse group (as appropriate to the study in question). With the emergence, accessibility, and widespread uptake of 'smart' sporting goods, which collect data during use, datasets should naturally become more diverse and inclusive than those collected during traditional research study settings (i.e. within a research laboratory).

A challenge is to appropriately manage the data collection and associated datasets so that they can be divided in such a way as to address research questions related to different user groups. Making such datasets open-access, while adhering to ethical and personal data protection requirements, would allow researchers to access them to address research questions that bring broad societal benefits. Undergraduate and postgraduate students studying science, technology, engineering, and mathematics must also be taught this throughout their degrees, along with the importance of ensuring appropriate ethics and having a valid research question and study design.

Invisible women

In 2019, Caroline Criado Perez published Invisible Women.[68] This book argues that there is a 'gender data gap' due to much of the world around us having been designed with males considered the default human and females atypical. It investigates the effect this has on women's lives at home, in the workplace, in medicine, and more.

It claims that women are 50% more likely to be misdiagnosed post heart attack and 17% more likely to die in a car crash. The book states that 'the medical system systematically discriminates against women, leaving them chronically misunderstood, and misdiagnosed'. Data typically collected pertains to men's experiences and not women's, and said data are used to allocate research funding and influence design.

In sport, an example given is that treadmills base their calorie counting on the average male body, meaning that it is inaccurate for women with implications for performance and health monitoring.

> "Data used to inform the design of sporting goods should represent a diverse population of users, to ensure the end product fits their needs.

Dr Katrine Okholm Kryger
Associate Professor in Sports Medicine at St Mary's University, Twickenham, and Medical Researcher at FIFA

Injury recovery devices

Richard Mills experienced an injury that ended his Sunday football career in 2009, and this inspired him to create ProMOTION EV1.[69] Developed with Sheffield University, the company describes it as 'innovative therapy on the move'. The device allows for recovery without ice, water, or heavy equipment and is fully portable. It uses contrast therapy by implementing both cooling and heating features and is strapped to the injured party in the area of injury using targeting therapy for recovery.

Sports Engineering in the UK

The UK is a world leader in sports engineering for many reasons. Sports engineering has a rich history in the UK, and the field is becoming increasingly organised. The first international conference on sports engineering, The Engineering of Sport, was held in Sheffield, England, in 1996.[70] The conference returned to Sheffield in 1998, when the International Sports Engineering Association (ISEA)[71] and its journal Sports Engineering were founded.[72] The biennial conference has been held in Sheffield three times, and the next one will be held at Loughborough University in July 2024.[73]

A third of the ISEA fellows, which is the highest grade of membership awarded based on sustained contributions to the field of sports engineering, are also UK-based. The IMechE encompasses sports engineering within the Biomedical Engineering Division.[74] The first issue of the Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology[75] was published in 2008.

> “The International Sports Engineering Association was founded in the UK, and the UK remains a leader in Sports Engineering.”
>
> **Professor Lloyd Smith, ISEA President**

Figure 2: Sports engineering in the UK

There are research groups focused on sports engineering within various UK universities. Some UK universities offer degree courses on sports engineering. The UK also has established sports engineering events and networks that foster research collaborations between academia and industry. Examples include:

- 'Innovation in sport: accelerating breakthroughs in engineering, optimisation and performance' at the Royal Society in 2022[76]
- The annual 'UK Sports Engineering Seminar Day' since 2017
- The UK Research and Innovation funded 'UK Metamaterials Network', which includes a health focus area[77]
- The 'SPORTSURF[78] network' , which focuses on sports surfaces

This high level of support, expertise, facilities, and networks ensures the UK remains a world leader in sports engineering research.

The UK also hosts some of the world's largest and most prestigious sporting events. Examples include the London 2012 Olympics and Paralympics, Cricket World Cup 2019, UEFA Women's Euro 2022, Birmingham 2022 Commonwealth Games, and, recently, the 2023 Cycling World Championships in Glasgow. The latter was the biggest cycling event ever, encompassing 13 world championships, for which Great Britain topped the medal table for both cycling and paracycling.[79] Hosting and excelling in such events can inspire the next generation of sports engineers and give those working in the UK various opportunities for research and practice.

These opportunities include supporting athletes with the design and implementation of their equipment and training tools, and designing and certifying sporting facilities, such as mountain bike trails, and officiating technologies. Long-running leagues and tournaments that also bring opportunities to the UK sports engineering community include Premier League Football, The Open Championship (The Open), and The Wimbledon Championships (Wimbledon).

The Open was founded in 1860 in St Andrews, and Wimbledon was founded shortly after, in 1877, making them the world's oldest golf and tennis tournaments, respectively. The R&A World Golf Museum is next to the Royal and Ancient Golf Club and the Old Course in St Andrews. The Wimbledon site houses the Wimbledon Lawn Tennis Museum. These museums have collections dating back to the origins of the sport, which researchers can access, including for studying how sporting technologies have developed.[80]

The UK's rich sporting history means that it is also home to various sporting governing bodies. These include the R&A (R&A Rules Limited) in St Andrews[81] and the ITF in London.[82] These governing bodies have sports engineering teams and test facilities. The previous IMechE policy report on sports engineering[1] describes how the ITF Technical Centre was established in 1997. The R&A (R&A Rules Limited) opened its current world-class testing and research facility at Kingsbarns, close to St Andrews, in 2017. These governing bodies undertake and oversee research on sporting technologies so that they can monitor developments and set appropriate rules and regulations to protect the nature of the game. Such research also allows them to embrace officiating technologies, such as automated line-calling in tennis.[83] They routinely monitor and test sporting goods and facilities and officiating technologies to ensure compliance with regulations. Sporting governing bodies also outsource such work and partner with test houses and research institutes.

There are UK-based test houses that contribute to the development of test methods, regulations, and standards for sporting goods and facilities and officiating technologies. These test houses also test such goods, facilities, and technologies to ensure compliance with sporting governing body regulations and relevant standards. In the UK, these standards are produced by the British Standards Institute. UK-based sports engineers have the opportunity to contribute to the development and implementation of various standards and regulations. Such regulations can include those of sporting governing bodies located abroad, such as FIFA and World Rugby. The previous IMechE policy report[1] recommended that sports engineers be involved in the continuous monitoring, reviewing, and updating of such regulations and standards. Involving sports engineers allows those managing the respective sports to make informed decisions about whether to embrace the latest technologies. Via their involvement in this process, UK-based sports engineers contribute to ensuring high sporting performance and fairness while reducing injury risk and enhancing player welfare.

The UK is ranked first in Europe for sports technology start-ups[4] and is home to a thriving industrial network of companies who develop sporting goods and facilities. These companies market various products such as balls, bats, bikes, clothing, footwear, playing surfaces and protective devices and materials. Some major international sporting goods brands, also have UK-based sports engineering facilities. Sporting goods brands such as these are represented by industry networks. Such networks include the Sporting Goods Industry Association, which represents manufacturers and distributors of sporting goods in the UK, and the Sports and Play Construction Association. There are also sports engineering consultants. A Northampton-based company is the only remaining last manufacturer in the UK, and it works with leading sports footwear brands.

UK Sport is the main organisation responsible for investing in Olympic and Paralympic sport in the UK. The previous IMechE policy report[1] outlined how UK Sport, and its network of partners, helped athletes prepare and compete using the latest technologies in the London 2012 Olympics and Paralympics. It also outlines the contributions of UK Sport to the development of a vibrant, world-leading sports engineering industry in the UK. Within UK Sport, the UK Sports Institute delivers support to athletes and teams, with a total of 36 million pounds of funding allocated to performance innovation across the last three Olympic and Paralympic Cycles (2016, 2020, and 2024).[84]

The Institute's performance innovation team works on innovations related to performance engineering and technical performance tools, as well as athlete health, coaching science, and performance science. Their innovation partners are BAE Systems and Sally Cowan Ltd.[85] Sport England, Sport Wales, Sport Scotland, and Sport Northern Ireland focus on community sport. There are also various sporting charities in the UK, including WheelPower, the national charity for wheelchair sport and the Football Foundation, who support the development of facilities for grassroots sport in England. Organisations such as UK Research and Innovation (UKRI) and the Royal Academy of Engineering (RAEng) provide funding to support research and development activities, including collaboration between academia and industry. These various organisations all contribute to the UK's thriving world-leading sports engineering community, which spans both research and practice.


FIFA WORLD CUP
Qatar2022
SPEEDSHELL

The future of technology and engineering in sport

This sub-section focuses on four main areas of innovation in sports engineering: 1) advanced materials, 2) digital and AI technologies, 3) officiating and fan engagement technologies, and 4) mechanical testing and engineering analysis.

Advanced materials

The previous IMechE policy report[1] outlined how advances in materials have improved sporting goods and, hence, athlete performance. It noted how fibre–polymer composites have improved pole vault poles, tennis racquets, and bike and wheelchair frames. These composites have high stiffness-to-mass ratios and can be formed into complex shapes. They allow items such as bikes and wheelchairs to be more aerodynamic, as confirmed by wind tunnels and CFD.[47] The report also noted improvements in swimsuits from synthetic materials, such as polyamide, elastane, and, later, polyurethane. The importance of nanotechnology and additive manufacturing (known as '3D printing') to sporting goods was also noted, with predictions that they have more to contribute.

The latest Sports Technology Annual Review[34] also notes the contributions of advances in materials. These contributions are related to graphene, as well as to making products more environmentally friendly. The Engineering and Physical Sciences Research Council (EPSRC) recognises the need to provide investment and support in materials by having an advanced materials theme.[86] Various research areas within the EPSRC theme align with those in the previous IMechE policy report[1] and the Sports Technology Annual Review. These areas include those focused on composites, polymers, graphene, and carbon nanotechnology. The EPSRC also co-funds the UK Metamaterials Network with the Innovate UK Knowledge Transfer Network (KTN) and the Defence Science Technology Laboratory, for which sport sits within the health theme. Other themes include sustainability and manufacturing, with implications for the UK sports engineering sector.

Graphene was discovered in the UK in 2004 by Professors Geim and Novoselov at the University of Manchester.[87] They were awarded the Nobel Prize for their discovery in 2010, which has featured in sporting goods, including tennis racquets[88] and footwear. With funding from Innovate UK KTN, a Lake District-based company worked with the University of Manchester to bring graphene to running shoes. They released shoes featuring graphene in the outsole in 2018 and in the midsole foam in 2021.[89] Associated patents describe a shoe sole made of a graphene-based compound, consisting of at least one elastomer and a graphene-based material of low percent weight.[90,91] These patents claim enhancements in grip, durability, and energy return.

Metamaterials are engineered structures with combinations of properties that cannot be achieved in the bulk materials from which they are made. These properties include cloaking of light, infrared radiation or acoustic waves, shape morphing, negative Poisson's ratio (they thicken when stretched), and negative stiffness. The ability to precisely design their response under various loads (e.g. impact, indentation, or vibration) makes mechanical metamaterials particularly relevant to sporting goods, including protective devices such as footwear, helmets, and body protection. The loads these products can experience are often complex and can include large, dynamic deformations, meaning that the range of required properties may not be available in conventional bulk materials. A London-based start-up applies mechanical metamaterials to sporting goods, utilising strain rate sensitive polymer technology developed at Imperial College.[92] It applies computational design to these polymers to create dynamic and reactive mechanical metamaterials.

Materials with a negative Poisson's ratio are called auxetic materials.[93] A review article published in 2018 by UK-based researchers outlines how auxetics could improve sporting goods.[94] The properties of auxetics that could bring improvements include synclastic (domed) curvature, high resistance to penetration by concentrated loads, and vibration damping. These UK-based researchers have worked with a major sporting goods brand to bring auxetic composites[95] to tennis and padel racquets.[96] Other examples of sporting goods featuring mechanical metamaterials include footwear,[97] helmets,[98] and body protection.[99] A recent review by the same team outlines how mechanical metamaterials could enhance helmets and reduce concussion risk.[100] Many mechanical metamaterials are cellular, and these cells form large internal features that are computationally expensive to simulate, particularly when factoring in the complex load cases that sporting goods can experience. A flourishing body of scientific development homogenises (or averages) the response of such metamaterials so that they can be simulated as bulk solids.[101] Sporting goods make an ideal testbed for such methods.

Metamaterials also have the potential to reduce the environmental impact of sporting goods. The enhanced properties of mechanical metamaterials are often gained by forming conventional materials into specific architectural structures. Such structures can be made via additive manufacturing, cutting, machining, or moulding. Enhancements gained from metamaterials could allow sporting goods to be made with fewer constituent materials or parts. Materials that are more environmentally friendly, such as those that are natural or bio-based, can have inferior properties to their conventional, often synthetic, counterparts. Using a metamaterials approach and structuring sustainable materials to mimic the properties of unsustainable ones could overcome these limitations, making them more suitable for use in sporting goods.

Metamaterials can also be smart or active, adapting their properties and shape to external stimuli. Such active metamaterials could increase accessibility by allowing sporting goods that adapt to the needs of the user. The embedding of electronics and actuators within sporting goods can, however, increase their environmental impact and make them harder to recycle. There is also a cost in developing metamaterials and implementing them into sporting goods, which can increase cost and limit accessibility. Such challenges can be overcome by investing in collaborative research efforts, as done with the UK Metamaterials Network.

Digital and AI technologies

The previous IMechE policy report[1] outlined how sensors are used in sports engineering research and athlete performance monitoring and enhancement. There has since been continued uptake and integration of wearable devices, 'smart clothing', body scanning, and machine vision tools within sport.[102] Such developments can facilitate the measurement and analysis of athletes and their equipment in a sporting scenario outside the traditional laboratory. The winner of the 'Equipment or Wearable of the Year' category of the 2022 Sports Technology Awards was a London-based consumer electronics company.[103] The award was for their digital ski coach, which takes measurements from pressure and inertial sensors in the boot to give audio feedback on technique via a smartphone app.[104]

The increased uptake and integration of electronics into sporting goods also brings environmental sustainability challenges. Extra material and manufacturing are needed to integrate electronics; energy is required to power them, typically from a battery, and they make disassembly for recycling harder. As such, sports engineers must make environmentally responsible decisions regarding sensors and other wearable devices. Developments in machine learning have made it possible to use sensors to infer information beyond that being measured.[105]

For example, machine learning algorithms have been used to predict running surfaces using measurements from an ankle-worn inertial sensor.[106] Such an ability to classify running surfaces with one sensor has implications for exercise monitoring devices. Machine learning allows information of interest to be inferred with fewer and less complex measurement devices, bringing new opportunities while reducing financial and environmental costs and increasing accessibility.

Developments in wireless network technologies, the Internet of things, and cloud computing have made it easier to synchronously collect and analyse data from sensors worn by different people.[107] Further improvements could come from standardisation of technologies to facilitate integration and synchronisation of sensors and software from different brands.[102] There is also a need for standards and unified guidelines for validating and using sensor technologies,[105] which could extend to sustainable and inclusive design considerations.

Such developments in wireless digital and AI technologies are leading to the generation of increasingly large datasets on athletes and their equipment. By collaborating with sporting teams or governing bodies routinely collecting such data, researchers can focus their efforts on analysing rather than collecting data. Advocates of open science[108] encourage making such datasets freely available, which increases research transparency and creates new opportunities. A current issue is the lack of diversity among the participants, who tend to be adult males, used in sports engineering studies and datasets in general.[52] This lack of diversity can create biases and lead to sporting goods that are unsuitable for a broad population of users. An inclusive design approach is preferred to ensure that sporting goods are suitable for as many people as possible. There is also a need for unified guidelines for applying machine learning in sport science and physical activity monitoring to reduce the risk of researchers making wrong or harmful decisions[105] and to improve the general classification of motions and scenarios.

Officiating and fan engagement technologies

Technology is increasingly being used to assist in officiating and enhancing fan engagement. The previous IMechE policy report[1] noted the use of line-calling technology in tennis. The developer has its headquarters in Basingstoke UK, and they have since developed their technologies to assist with officiating in various sports, including at the Olympics and FIFA World Cup.[109] Various officiating and fan engagement technologies are now used in football competitions. These technologies include Goal-Line Technology, Video Assistant Referee Technology, Offside Technology, and Electronic Performance and Tracking Systems.[110] The technological approach varies between providers and tends to be optical or wearable sensor-based.

The ball of the FIFA World Cup Qatar 2022™ had an internal sensor, which was used as Offside Technology.[111] When combined with player tracking and event detection systems,[112] such a ball could provide valuable information on game dynamics, with implications for fan engagement, athlete training, and the design and regulation of sporting goods and facilities. Decisions on the regulation and implementation of such technologies must be supported by peer-reviewed scientific evidence.[113] As such, there are many opportunities for sports engineers to work on the development, regulation and certification of officiating, and fan engagement technologies. Such technologies should be designed to be low-cost and inclusive, so they are accessible for lower-level competitions and less affluent sports.

The lines between traditional and e-sport are blurring with the rise of hybrid sport, which is sometimes known as evergaming or mixed reality. The latest Sports Technology Annual Review notes two examples of hybrid sports: One of these is a smart trainer and the associated app that allows a cyclist on a static bike to explore virtual worlds, train, and compete with people located elsewhere.[114] Hybrid sport like this can help widen participation, as people can engage in sport with others from virtually any location.

Hybrid sports also bring extra challenges to equipment regulation and certification, particularly at the elite level, to ensure fair competition.[115] A soon-to-launch golf league will see elite golfers competing in a mixed-reality environment in a stadium with people watching both live and virtually.[116] The competition will utilise golf simulator.[117] The technologies used to measure the movement of each golfer, their equipment, and the models used to predict ball flight, impact, and rolling behaviour must be as realistic as possible to ensure fair competition and encourage athlete and fan engagement.

Mechanical testing and engineering analysis

Sports engineers use various mechanical tests when researching, designing, regulating, and certifying sporting goods and facilities.[118] There is continual work to ensure that such tests are representative, so the findings are applicable to the intended sporting scenario. These mechanical test methods are often informed by qualitative and quantitative data collected during studies with participants during simulated or actual sport. The movements and loading patterns of participants in such studies are typically captured with the aid of optical or sensor-based motion-tracking systems.[102] Such research is often undertaken as a collaboration between academia, industry, and sporting governing bodies. For example, researchers from such organisations used feedback from footballers on the attributes of different sports surfaces to inform recommendations for updating test rigs for certifying pitches.[14]

Human limb surrogates used for the mechanical testing of sporting goods must be sufficiently realistic, and there is a particular need to ensure that tests related to the safety of athletes correspond to relevant injury risk scenarios. These tests can include those related to certifying sporting facilities, such as pitches, or protective devices, such as helmets and body protection. Certification tests for protective devices often use a fixed metal of an overly simplistic shape to represent a human limb.[119]

There is ongoing research to develop human limb surrogates of more representative shapes and soft tissue simulants to provide a more realistic response to loading.

A noteworthy example of a human limb surrogate is the (patent pending[120]) Loughborough University surrogate neck.[121] The neck is designed to be attached to a headform for testing protective headgear. It is intended to overcome the limitations of the overly stiff surrogate necks developed for automotive crash applications. There is also a need to ensure that such surrogates are scaled and adapted to represent a diverse population, including women and young people, who are often overlooked in place of the typical adult male.[122] It is particularly important to ensure surrogates represent diverse populations in certification tests for protective devices, which must balance realism with simplicity to ensure repeatability and low-cost accessibility.

Additive manufacturing has helped engineers to develop better human limb surrogates[123] and sporting goods. Advances in engineering software, and computing in general, have also aided sports engineers in developing better surrogates and sporting goods. Computational design software, and generative AI, can help sports engineers develop concepts and complex geometries for novel sporting goods. These concepts can then be iteratively simulated, prototyped, tested, and improved. For example, such tools are used when developing mechanical metamaterial lattices for application in sporting goods. Other developments helping sports engineers to efficiently devise new solutions include cloud-based computer-aided engineering software, enhanced optimisation tools, open-source software, and homogenised data sets, such as meta-genome.[124]

Recommendations

More testing facilities for researchers

Recommendation 1: Increased investment in facilities for research related to mechanical testing of sporting goods and testing technology in sporting scenarios.

The UK lacks easily accessible facilities for researchers and innovative sports engineering companies to conduct the research required to develop sporting technologies. At least two new hubs would fill this gap.

The first hub would focus on research related to the mechanical testing of sporting goods. This is an area where there is a gap between market demands, certification requirements, and user/environment variability, which is known to increase injury risk and to disadvantage women sports participants and other underserved groups.

The second hub could focus on research related to the conducting of tests in environments that closely match real-world sporting conditions. At present, a lack of ringfenced funding prevents high-performance technology developed for elite sport from transferring to recreational exercise, healthcare, and active travel, and this hub would help fill that gap.

The two hubs could serve as beacons of excellence, attracting and clustering global talent and sporting governing bodies and industry from start-ups to major international brands.

These major international brands would bring income and multifaceted long-term projects. Dedicated staff within each hub would enable efficient collaboration with such external partners. The hubs would offer transparency of results to their partners, as well as guidance and recommendations following testing. They could include libraries of devices for loans, such as portable test rigs, surrogates and headforms, cameras, inertial measurement units, and pressure insoles. The UK sports engineering sector would benefit from these hubs if they could access the facilities in a timely manner at a reasonable cost. Time at the hubs could be included in grants and UK-based startups, and small- and medium-enterprises could have subsidised access. Support of this nature would allow the UK sports engineering community to focus effort and resources on developing novel solutions to societal challenges.

Technology transfer from elite sport to community sport

Recommendation 2: More funding for schemes to transfer technologies developed for elite sport into the community for wider societal benefit.

Public funds spent on elite sport should have clear societal benefits. Transferring technologies developed for elite sport to the wider sporting community benefits society, including widespread improvements in physical and mental health. This could be achieved by providing the UK Sports Institute with a specific budget for elite-to-community technology transfer in collaboration with industry and academia. The focus should be on making elite sports technology accessible and affordable after competitions, following the initial need for secrecy to protect a competitive advantage.

Elite sport could also serve as an excellent showcase of the benefits of sustainable sporting goods and foster a 'sustainable is elite' culture within the UK and globally. Such a campaign could, for example, involve British cyclists winning competitions while riding bikes made from natural, recycled, or otherwise sustainable materials. Resources should be provided to help transfer sustainable sporting goods from elite sport to consumer products, deliver better integration between parasport and health services, and transfer elite parasport technologies to the wider community. Engineers working in elite sport should also be supported and encouraged to publish the knowledge they have generated, via peer-reviewed conference and journal articles, when the competition and hence competitive advantage has passed.

Encouraging sustainable sporting goods

Recommendation 3: Encouragement of sports technology providers by governing bodies to embrace independently audited ecolabels that will help transition to more sustainable materials and manufacturing.

Many governing bodies have enormous influence over sporting goods brands. They check the performance of the brands products against their regulations to determine whether they are eligible for use in competition, which influences consumer acceptance and sales potential. Sporting goods used in major sporting competitions have elite status that allows brands to charge more for their products. By enforcing high environmental standards alongside performance requirements, particularly to mass-produced products with short lifespans, governing bodies could reduce the environmental impact of their sports.

Governing bodies could embrace ecolabels as a mechanism to achieve this. For example, they could only consider products for performance approval that have an independently certified and audited ecolabel from an established and reputable scheme, such as the EU Ecolabel. Collaborative work is likely needed to ensure current ecolabel schemes align to sporting goods categories and the requirements of governing bodies. Collaboration between the organisations developing sporting goods and those responsible for waste management would also help facilitate reuse and recycling. An uptake of ecolabels within the sporting goods and facilities sector would ultimately help retailers and consumers to make informed choices about sustainability, in a similar way to how safety standards give confidence when purchasing protective devices.

An open science approach

Recommendation 4: Encouragement of open-access, standardised data as the norm in the field of sports engineering.

To ensure that sporting technologies meet the needs of as many people as possible, data must be taken from a wide and diverse group. More open-access databases would help achieve this. Making such datasets publicly available, while adhering to ethical and personal data protection requirements, would also boost research in the field and bring broad societal benefits.

Support should be provided to sports engineers to ensure that they are trained in collecting data with participants ethically and responsibly and handling and processing associated datasets. Such support could include accessible expert guidance, training, and continued professional development (CPD) resources developed in collaboration with domain experts and associated organisations. These organisations could include the British Association of Sport and Exercise Sciences, the International Society of Biomechanics in Sports, and the Royal Statistical Society and the Sustainable Software Institute. Resources related to data collection with athletes could cover topics such as ethics, inclusivity, selection of participants, and selection and validation of measurement devices. Resources related to data could include the handling and sharing of datasets, statistics, including machine learning and AI, and sustainable software.

Support for transdisciplinary collaborations

Recommendation 5: A UK sports engineering network to support transdisciplinary collaborations needs to be established.

Sports engineering innovations can be top-down or bottom-up, meaning they can either be pushed by sports engineers or pulled by the sports market. As such, the rapid uptake sporting goods sector is an ideal place to i) trial and develop new technologies and ii) adopt technologies from other sectors into the mass-produced sporting goods market (e.g. fibre-reinforced composites and additive manufacturing).

A new UK sports engineering network would support multidisciplinary collaborations and greater participation of women and other underserved groups in sports engineering. It would provide funding for hosting and attending meetings and events, including sustained funding for the UK Sports Engineering Seminar Day.

Resources should be allocated to transdisciplinary user-centred research and development activities. Support could be provided for networking, including national and international activities, such as visits to leading academic facilities, companies, and governing bodies, and conferences and events. Academic researchers and sporting goods brands could also be supported by promotional and advertising opportunities to showcase their innovative sporting technologies and attract international collaborations and businesses. This could include dedicated sports engineering trade shows and targeted government promotional campaigns, as well as initiatives for raising awareness of the capabilities and potential of new underpinning technologies, such as metamaterials.

Support should also be provided specifically to mentor and support women and other underserved groups in the sports engineering sector to help bridge the engineering equality gap and ensure nobody is overlooked in research and development. UK-based sports engineers would also benefit from support for fundamental research in science, technology, engineering, arts, and mathematics, including areas such as aerodynamics, biology, biomechanics, chemistry, machine vision and machine learning, materials, modelling and simulation, physics, product design, robotics, sensors and instrumentation, and solid mechanics. Researchers could also be encouraged and supported in using sports engineering examples, such as case studies of novel technologies in grants and projects. Such case studies could feature in public engagement projects to help raise awareness of sports engineering excellence in the UK.

Conclusion

Support and investment in collaborative research and development are required to ensure that the UK remains world-class in sports engineering. Sports engineers must work interdisciplinarily on complex societal problems within transdisciplinary teams, often including experts from academia, industry, and governing bodies. To remain world class, these sports engineers must have access to state-of-the-art knowledge and facilities, including for simulating and testing sporting goods and collecting data during actual sport. The problems that sports engineers work on often require consideration of sustainability and inclusivity issues, expertise in working with participants and handling associated data, and the implementation of state-of-the-art technology and computational methods. Sports engineers must, therefore, engage in CPD and receive training in the latest methodologies and technologies. This could include sustainable and inclusive design practices, as well as work ethically and responsibly with participants, including handling and storing data. UK-based sports engineers must also have opportunities to meet and network with world-leading experts from other sectors, so they can develop and showcase their ideas and technologies. By providing such opportunities, the UK sports engineering sector will remain attractive to the next generation of sports engineers, as well as established global talent.

References

1 IMechE. (2012). Sports engineering: An unfair advantage.

2 https://www.hire-intelligence.co.uk/evolution-of-technology-in-sport/

3 Chamberlain, M. et al. (2023). Development of a bicycle crank arm demonstrator via Industry 4.0 principles for sustainable and cost-effective manufacturing. Sports Engineering, 26(1), p.2.

4 https://www.great.gov.uk/international/content/investment/sectors/sports-economy/

5 https://www.statista.com/statistics/319296/number-ofpeople-with-sports-occupations-in-the-united-kingdom-uk/

6 STA Group (2020). The 2020 Sports Technology Annual Review

7 https://www.forbes.com/sites/jonquilhackenberg/2021/09/09/why-we-need-to-make-sport-more-sustainable/?sh=3647fa78165c

8 https://www.uksport.gov.uk/our-work/powering-positive-change-and-social-impact/environmental-sustainability#:~:text=On%2028%20March%20 2023%2C%20UK,on%20the%20environment%20by%20 2040

9 https://www.bicycling.com/tour-de-france/a44418276/uciannounced-a-mandatory-emissions-reduction-for-worldtour-teams/

10 Wilby, R.L. et al. (2023). The impacts of sport emissions on climate: Measurement, mitigation, and making a difference. Annals of the New York Academy of Sciences, 1519(1), pp.20–33.

11 https://carbonliteracy.com/what-is-the-carbon-footprint-of-sport/

12 Jim, C.Y. (2017). Intense summer heat fluxes in artificial turf harm people and environment. Landscape and Urban Planning, 157, pp.561–576.

13 https://sustainable.golf/about/certification/

14 Cole, D. et al. (2023). Development and evaluation of a sensory panel for collecting reliable player perceptions of third-generation synthetic turf football surfaces. Sports Eng 26, p.7.

15 European Commission (2022). EU Strategy for Sustainable and Circular Textiles.

16 https://esg.exerica.com/Company?Name=Adidas

17 https://www.statista.com/statistics/1322509/ghg-emissions-from-nike-by-scope/

18 https:www.statista.com

19 Statista (2022). Sporting goods in the United Kingdom (UK). [Online]. Available: https://www.statista.com/study/25808/sporting-goods-in-theunited-kingdom-uk-statista-dossier/

20 Mine Akin (2023). Footwear Report 2023, Statista Consumer Market Insights, April 2023.

21 https://www.runnersworld.com/gear/a33233314/how-manymiles-do-running-shoes-last/

22 Titirici, M. et al. (2022). The sustainable materials roadmap. Journal of Physics: Materials, 5(3), p.032001.

23 https://www.europarl.europa.eu/news/en/pressroom/20230609IPR96210/making-batteries-moresustainable-more-durable-and-better-performing

24 Allen, T. et al (2020). Effect of Rest Periods on Mechanical Ageing of Running Shoes. In Proceedings (Vol. 49, No. 1).

25 Lippa, N. (2014). Mechanical ageing protocol selection affects macroscopic performance and molecular level properties of ethylene vinyl acetate (EVA) running shoe midsole foam. Procedia Engineering, 72, pp.285–291.

26 Lippa, N.M. (2017). Biofidelic mechanical ageing of ethylene vinyl acetate running footwear midsole foam. Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, 231(4), pp.287–297.

27 Lippa, N.M. (2017). Mechanical ageing performance of minimalist and traditional footwear foams. Footwear Science, 9(1), pp.9–20.

28 https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en

29 DfT (2021). Decarbonising Transport: A Better, Greener Britain.

30 https://commission.europa.eu/live-work-travel-eu/consumer-rights-and-complaints/enforcement-consumer-protection/sweeps_en

31 Taraborrelli, L. et al. (2019). Materials have driven the historical development of the tennis racket. Applied Sciences, 9(20), p.4352.

32 Hébert-Losier, K. and Pamment, M. (2023). Advancements in running shoe technology and their effects on running economy and performance–a current concepts overview. Sports Biomechanics, 22(3), pp.335–350.

33 https://worldsailingtrust.org/carbon-fibre-circular-alliance

34 STA Group (2022). The 2022 Sports Technology Annual Review.

35 https://www.nike.com/gb/sustainability/materials

36 https://www.textilegence.com/en/the-worlds-first-bio-basedspandex-is-ready-for-sale/

37 https://www.adidas.co.uk/blog/639412-how-we-turn-plastic-bottles-into-shoes-our-partnership-with-parley-for-the-oceans

38 https://www.on-running.com/en-gb/collection/cyclon

39 https://www.fis-ski.com/en/international-ski-federation/newsmultimedia/news-2022/fis-to-fully-implement-fluor-wax-banat-start-of-2023-24-season

40 https://renewaball.com/

41 Facts and Figures / FAQ – The Championships, Wimbledon - Official Site by IBM.

42 https://www.e-nano.io/

43 https://www.justice.gov/crt/title-ix

44 https://www.thisgirlcan.co.uk/

45 https://www.nationalgeographic.co.uk/history-and-civilisation/2021/09/how-the-paralympic-movement-evolved-into-a-major-sporting-event

46 https://www.paralympic.org/classification

47 Crouch, T.N. et al. (2017). Riding against the wind: A review of competition cycling aerodynamics. Sports Engineering, 20, pp.81–110.

48 https://everybodymoves.org.uk/

49 Koptyug, A. and Burkett, B. (2016). Editorial for the special issue technology for disability sport. Sports Eng 19, 139.

50 https://www.invictusgamesfoundation.org/

51 https://www.sir.advancedleadership.harvard.edu/articles/shrink-it-and-pink-it-gender-bias-product-design

52 Okholm Kryger, K. et al. (2022). Ten questions in sports engineering: Technology in elite women's football. Sports Engineering, 25(1), p.25.

53 Chia, L. et al. (2022) Non-contact anterior cruciate ligament injury epidemiology in team-ball sports: A systematic review with meta- analysis by sex, age, sport, participation level, and exposure type. Sports Med 52, p.2447–2467.

54 Prodromos, C.C. et al. (2007). A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury–reduction regimen. Arthroscopy: The Journal of Arthroscopic & Related Surgery, 23(12), pp.1320–1325.

55 https://www.theguardian.com/football/2023/jun/27/female-players-pain-wearing-football-boots-european-club-association-study

56 https://committees.parliament.uk/committee/328/women-and-equalities-committee/news/196873/why-arethere-so-few-female-specific-football-boots-and-doesthis-impact-on-the-prevalence-of-acl-injuries-football-bootbrands-respond-to-mps/

57 https://www.ispo.com/en/ispo-brandnew/2022/ida-sports-football-boots

58 https://committees.parliament.uk/work/977/concussion-insport/publications/

59 https://www.ox.ac.uk/news/2021-09-22-university-oxford-launches-podium-analytics-institute-youth-sports-medicine-and

60 https://www.drakefoundation.org/rugby-concussions/

61 https://www.gov.uk/government/publications/government-response-to-the-digital-culture-media-and-sport-select-committee-report-on-concussion-in-sport/government-response-to-dcms-select-committee-report-on-concussion-in-sport#annexa

62 https://www.opro.com/news/post/opro-plus-press-release

63 Gerwyn, T.G. et al. (2021). Novel technology in sports biomechanics: some words of caution. Sports Biomechanics.

64 Greybe, D.G. et al. (2020). Comparison of head impact measurements via an instrumented mouthguard and an anthropometric testing device. Sports Eng 23, p.12.

65 https://www.world.rugby/news/875212/world-rugby-integrates-smart-mouthguard-technology-to-the-head-injury-assessment-as-part-of-new-phase-of-global-player-welfare-measures

66 https://www.world.rugby/news/627598/world-rugby-exploring-latest-eye-tracking-technology-assist-with-identification-and-management-concussion

67 Haid, D. et al. (2023). Free-fall drop test with interchangeable surfaces to recreate concussive ice hockey head impacts. Sports Eng 26, p.25.

68 Criado Perez, C. (2019). Invisible Women: Exposing Data Bias in a World Designed for Men. Chatto & Windus.

69 https://promotion.fitness/

70 Haake, S. ed. (2020). The engineering of sport. CRC Press.

71 https://www.sportsengineering.org/

72 https://www.springer.com/journal/12283

73 https://www.lboro.ac.uk/research/sti-isea-2024

74 https://www.imeche.org/industry-sectors/biomedical-engineering

75 Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology: Sage Journals (sagepub.com)

76 https://royalsociety.org/science-events-and-lectures/2022/11/innovation-in-sport-tof/

77 https://metamaterials.network/focus-areas/health/

78 https://sportsurf.lboro.ac.uk/sportsurf-network/

79 https://www.britishcycling.org.uk/article/20230814-Home-Page-Record-crowds-attend-biggest-cycling-event-ever-as-inaugural-UCI-Cycling-World-Championships-come-to-a-close-0

80 Grant, R.A. et al. (2022). Morphometrics for sports mechanics: Showcasing tennis racket shape diversity. Plos One, 17(1), p.e0263120.

81 https://www.randa.org/en/equipment

82 https://www.itftennis.com/en/about-us/tennis-tech/

83 https://www.itftennis.com/media/7203/line-calling.pdf

84 https://www.uksport.gov.uk/

85 https://uksportsinstitute.co.uk/commercial-partners/

86 https://www.ukri.org/what-we-do/our-main-funds-and-areas-of-support/browse-our-areas-of-investment-and-support/advanced-materials-theme/

87 https://www.europarl.europa.eu/news/en/headlines/economy/20150603STO62104/graphene-the-wonder-material-of-the-21st-century

88 https://www.head.com/en_US/sports/tennis/technology/graphene360plus

89 https://www.manchester.ac.uk/collaborate/businessengagement/knowledge-exchange/case-studies/graphene-innovation/

90 https://patentimages.storage.googleapis.com/c7/a5/e3/617825abf276df/US11627777.pdf

91 https://patentimages.storage.googleapis.com/df/31/14/102b84d516566e/GB2604590A.pdf

92 https://rheonlabs.com /

93 https://www.bbc.co.uk/programmes/p02jfq9q

94 Duncan, O. et al. (2018). Review of Auxetic Materials for Sports Applications: Expanding Options in Comfort and Protection, Applied Sciences.

95 Alderson, K.L. et al. (2005). How to make auxetic fibre reinforced composites. Physica Status Solidi (b), 242(3), pp.509–518.

96 https://www.head.com/de_CH/rs/stories/auxetic-the-science-behind-the-sensational-feel

97 https://patents.google.com/patent/US9402439B2/en

98 https://wavecel.com/

99 https://www.iom3.org/resource/raising-the-bar-advanced-materials-in-sport.html

100 Haid, D. et al. (2023). Mechanical metamaterials for sports helmets: Structural mechanics, design optimisation, and performance. Smart Materials and Structures.

101 Van Der Giessen, E. et al. (2020). Roadmap on multiscale materials modeling. Model. Simul. Mater. Sci. Eng., 28(4).

102 Allen, T., et al. (2021). Wearables for disabled and extreme sports. Digital Health. Academic Press, p.253-273.

103 https://www.sportstechgroup.org/sports-technology-awards/past-winners/

104 Czaja, S. (2020). Method and apparatus to provide haptic and visual feedback of skier foot motion and forces transmitted to the ski boot. US Patent; 9,968,840, 2018.

105 Mundt, M. (2023). Bridging the lab-to-field gap using machine learning: A narrative review. Sports Biomechanics, pp.1–20.

106 Worsey, M.T. et al. (2021). Automatic classification of running surfaces using an ankle-worn inertial sensor. Sports Engineering, 24(1), p.22.

107 Perrotta, A.S. et al. (2023). Precision and Reliability of the Polar Team Pro Computer Software for Analyzing Heart Rate Variability. Sports Engineering.

108 Halperin, I. et al. (2018) Strengthening the practice of exercise and sport-science research. IJSPP 13(2).

109 https://www.hawkeyeinnovations.com/about

110 https://www.fifa.com/technical/football-technology

111 https://www.fifa.com/tournaments/mens/worldcup/qatar2022/media-releases/introducing-al-hilm-the-officialmatch-ball-of-the-fifa-world-cup-qatar-2022-finals

112 Vidal-Codina, F. et al. (2022) Automatic event detection in football using tracking data. Sports Eng 25, 18 (2022).

113 Billingham, J. and Dunn, M. (2023). Topical collection on football research. Sports Eng 26, p.35.

114 https://uk.zwift.com/

115 https://www.uci.org/docs/default-source/rules-and-regulations/11.12-uci-cycling-esports-regulations-en-22.01.2020.pdf

116 https://tglgolf.com/

117 https://www.golfdigest.com/story/tgl-tiger-woods-rory-mcilroy-primetime-golf-show-debuts-in-january-full-swing-tmrw-sports

118 Senner, V. (2022). History, philosophy, and value of mechanical models in sports science and engineering. Proceedings of the Institution of Mechanical Engineers, Part P. Journal of Sports Engineering and Technology.

119 Payne, T. et al. (2013). Design of human surrogates for the study of biomechanical injury: A review. Critical Reviews™ in Biomedical Engineering 41.1.

120 Farmer, J. et al. (2023). Neck assembly and uses thereof. U.S. Patent Application 17/916,149, Loughborough University.

121 Farmer, J. et al. (2022). A human surrogate neck for traumatic brain injury research. Frontiers in bioengineering and biotechnology, 10, p.854405.

122 https://www.theguardian.com/lifeandstyle/2019/feb/23/truth-world-built-for-men-car-crashes

123 Koptyug, A. and Bäckström, M. (2023). Body part surrogates for medicine, comfort and safety applications. Advances in 3D Printing. IntechOpen.

124 https://meta-genome.org/

Image credits: Cover/01: istockphoto.com/Edwin Tan; 02: istockphoto.com/Pengranger; 04: PCN Photography/Alamy Stock Photo; 06: istockphoto.com/Jacoblund; 08: PA Images/Alamy Stock Photo; 10: © adidas AG; 17: © E-Nano Ltd; 18: istockphoto.com/SolStock; 22: © PING; 26: © ProMOTION; 30: © FIFA; 40: Tribune Content Agency LL /Alamy Stock Photo

Institution of Mechanical Engineers

1 Birdcage Walk
Westminster
London SW1H 9JJ

+44 (0)20 7973 1293
media@imeche.org
imeche.org