applied sciences

MDPI

Review

Review on Wearable Technology in Sports: Concepts, Challenges and Opportunities

Ahmet Çağdaş Seçkin [1,*], Bahar Ateş [2] and Mine Seçkin [3,4]

[1] Computer Engineering Department, Engineering Faculty, Aydın Adnan Menderes University, Aydın 09100, Türkiye
[2] Faculty of Sport Science, Uşak University, Uşak 64100, Türkiye; bahar.ates@usak.edu.tr
[3] Textile Engineering, Engineering Faculty, Uşak University, Uşak 64100, Türkiye; mine1seckin@gmail.com
[4] Physiotherapy Department, Aydın Vocational School of Health Services, Aydın Adnan Menderes University, Aydın 09100, Türkiye
* Correspondence: acseckin@adu.edu.tr

Abstract: Wearable technology is increasingly vital for improving sports performance through real-time data analysis and tracking. Both professional and amateur athletes rely on wearable sensors to enhance training efficiency and competition outcomes. However, further research is needed to fully understand and optimize their potential in sports. This comprehensive review explores the measurement and monitoring of athletic performance, injury prevention, rehabilitation, and overall performance optimization using body wearable sensors. By analyzing wearables' structure, research articles across various sports, and commercial sensors, the review provides a thorough analysis of wearable sensors in sports. Its findings benefit athletes, coaches, healthcare professionals, conditioners, managers, and researchers, offering a detailed summary of wearable technology in sports. The review is expected to contribute to future advancements in wearable sensors and biometric data analysis, ultimately improving sports performance. Limitations such as privacy concerns, accuracy issues, and costs are acknowledged, stressing the need for legal regulations, ethical principles, and technical measures for safe and fair use. The importance of personalized devices and further research on athlete comfort and performance impact is emphasized. The emergence of wearable imaging devices holds promise for sports rehabilitation and performance monitoring, enabling enhanced athlete health, recovery, and performance in the sports industry.

Keywords: wearable; physiological sensors; sport; bibliographic analysis; injury prevention; sports; team; swing; data types; rehabilitation; anatomy

Citation: Seçkin, A.Ç.; Ateş, B.; Seçkin, M. Review on Wearable Technology in Sports: Concepts, Challenges and Opportunities. *Appl. Sci.* **2023**, *13*, 10399. https://doi.org/10.3390/app131810399

Academic Editor: Jorge E. Morais

Received: 10 August 2023
Revised: 11 September 2023
Accepted: 14 September 2023
Published: 17 September 2023

1. Introduction

The concept of Wearable Technology (WT) has been used in various fields such as healthcare, sports, entertainment, electronics, textiles, and the defense industry for a long time [1–5]. Thanks to the opportunities provided by sensor and internet technology, WT has made significant progress in the last two decades and ha become devices that we frequently use in our daily lives.

Various definitions have been proposed for the concept of WT, and it is an interdisciplinary field that involves disciplines such as engineering, healthcare, and sports. Godfrey et al. described the concept of WT by focusing on smartwatches and stating that it encompasses numerous devices that are directly or loosely worn on a person [2]. According to Seçkin et al., WT refers to non-invasive devices and sensors that individuals can wear on their bodies to assist in monitoring their health conditions, without requiring subcutaneous applications [5]. Shen et al. defined the concept of WT as mobile electronic devices that can be comfortably worn on the user's body or attached to their clothing [6]. Park et al., stated that WT devices differ from traditional clothing and enable personalized mobile computing [4]. Coyle and Diamond emphasized that WT devices should be soft, flexible, and washable, and they should meet people's expectations of normal clothing [7]. Ye et al., defined the concept of WT, which they examined as smart textiles, as fabrics with various integrated electronic components. They emphasized that this technology should meet the fundamental requirements of clothing, such as comfort, lightweight, thermal insulation, and breathability [8]. The common underlying point identified in these studies, in addition to direct definitions, is that WTs should incorporate sensors, processing units, power sources, and be wearable on the body. It is observed in some review papers that various sports equipment are also considered as wearable [3,9]; however, these are not actually wearable on the body and fall into the category of smart equipment, such as a smartphone or remote control device. From this perspective, it is crucial to define the boundaries of wearability clearly. Taking the above definitions together, WT can be described as devices that are worn on the body, non-invasive, and incorporate various electronic components such as sensors, communication units, processors, actuators, and power sources.

WT is revolutionizing sports by providing real-time data for athletes to improve training, enabling coaches to tailor strategies, and providing insights for the sports industry. This article explores the potential of WT in sports, highlighting its potential to enhance athletic prowess, enhance safety, and provide more engaging sports experiences for fans and stakeholders. The article aims to pave the way for future research in this dynamic field, highlighting the potential of WT in addressing various challenges in the sports industry. The aim of this article is to review the concept of WT in the field of sports, its components, applications, academic research conducted in this area, and highlight the challenges and future directions. The method followed is a literature review and compilation study. A search was made in the Web of Science (WoS) database using keywords in order to examine and compile academic research on the subject. Looking at the titles of the articles, it is seen that firstly, a literature analysis was made, then information about the hardware and software components of WT was given, and then a general evaluation of the anatomical structure of WT and available commercial products was made. Then, the applications of WT in the field of sports are discussed in detail, and finally, there is a Conclusions Section 9 in which the important points of the article are summarized, the difficulties encountered are discussed and suggestions for future research are presented.

2. Bibliographic Analysis of WT in Sports

In the bibliographic study, a search was conducted on the Web of Science (WoS) using the keywords "wearable" or "wearables" and "sport" or "sports." The search query was refined to include articles published between 2015 and 2023, in English, and indexed in either the Social Sciences Citation Index (SSCI) or the Science Citation Index Expanded (SCI-E), with the article type limited to papers. As a result, 2568 papers were found. Query criteria are limited, and only certain keywords and publication dates are used. Therefore, some relevant studies may have been overlooked during the screening process. The journals in which studies on sports and wearables are published are presented in Figure 1. Accordingly, the magazine with the most publications is Sensors with 287 publications. The number of publications per year is presented in Figure 2, showing an increasing trend over the years. Since this paper was submitted before the completion of 2023, the 165 articles from that year are excluded from the graph.

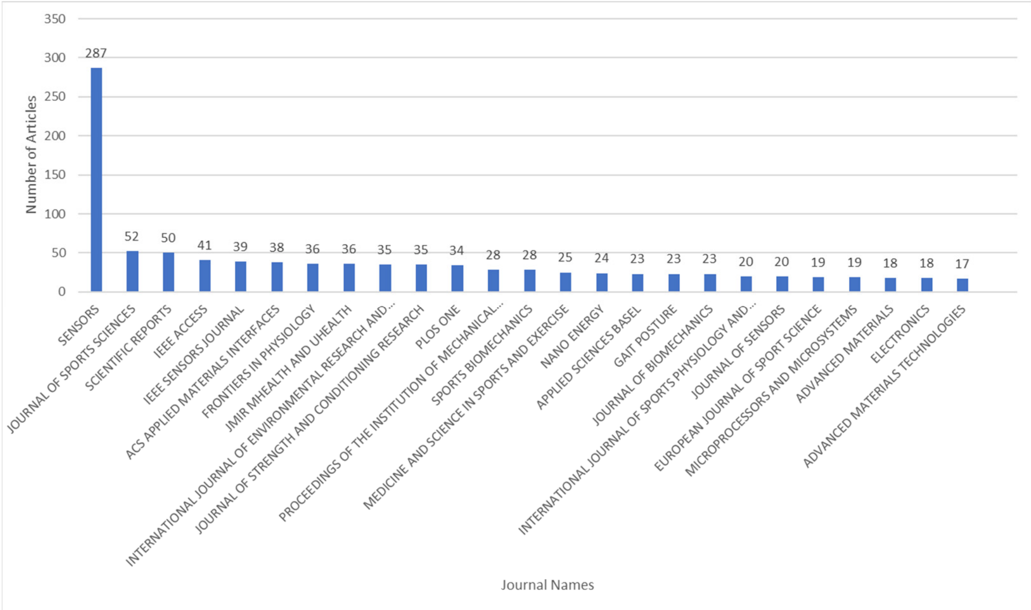

Figure 1. Number of Article by Journals.

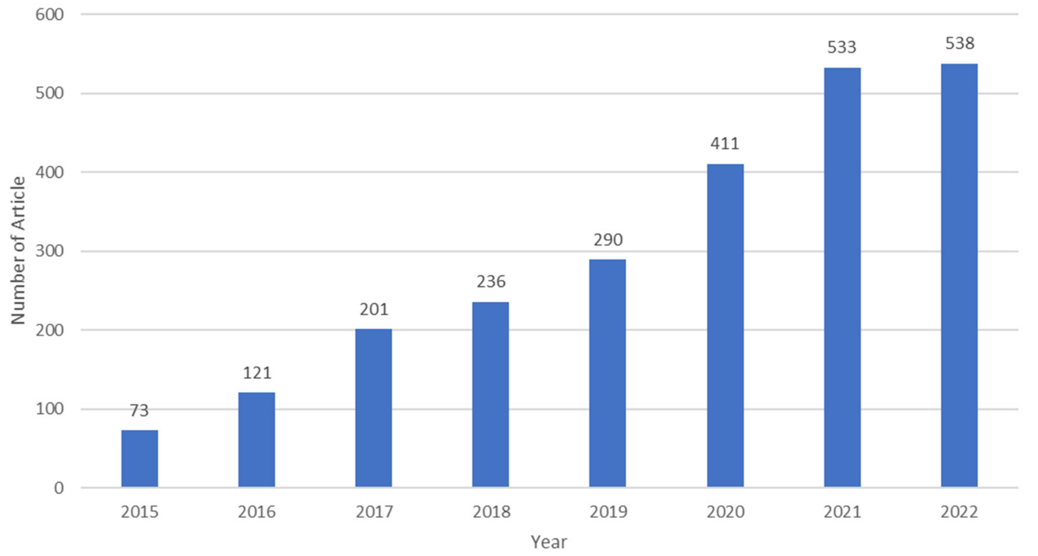

Figure 2. Number of Articles by Year.

In the context of academic inquiry utilizing the Web of Science (WoS) database, an examination of research areas pertaining to wearables and sports reveals key insights, as illustrated in Figure 3. This figure presents a ranked list of the top twenty research fields along with their corresponding article counts, arranged in descending order. According to Figure 3, the foremost four research areas, in terms of publication frequency, encompass engineering (34.93%), chemistry (21.46%), instrumentation (16.75%), and sport science (16.75%). The realm of research concerning WT predominantly operates within a framework comprising three fundamental dimensions: conceptual design, usage experimentation, and performance analysis. Within the domain of conceptual design, investigations are centered on factors such as sensor utilization, sensor placement, and overarching design considerations. These inquiries are primarily conducted within the domain of engineering studies. In contrast, endeavors related to usage experimentation involve the systematic evaluation of fully developed conceptual designs within meticulously selected and well-defined user cohorts. This category of research assumes an interdisciplinary character, drawing expertise from diverse domains, including physical education, engineering, and health sciences. Performance studies, conversely, are primarily characterized by investigations carried out using wearables that have attained a level of commercial maturity. In the context of these inquiries, the central focus is directed toward the assessment of athlete performance, with coaching emerging as a prominent field where experts in physical education make substantial contributions. Within the purview of these studies, the engineering component primarily finds application in specialized domains, notably computer science and data analysis.

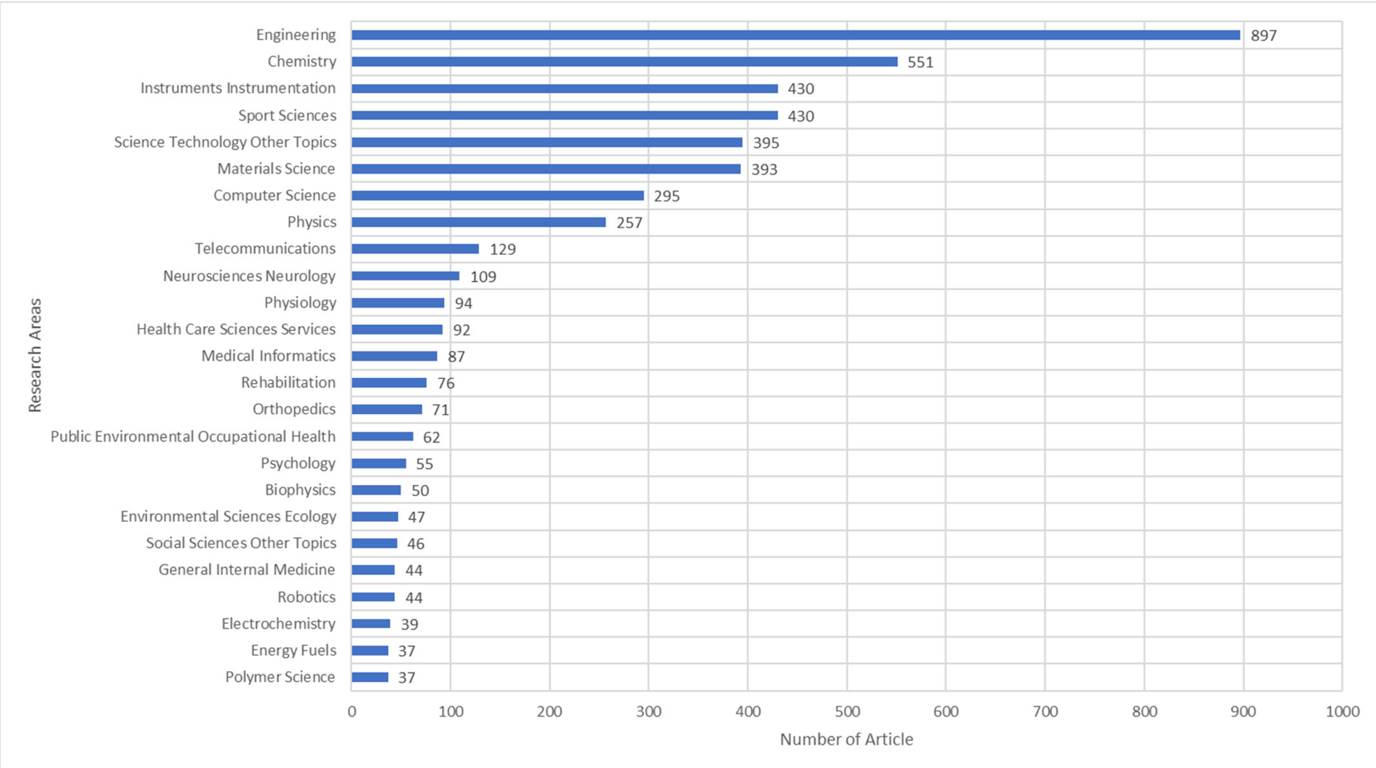

Figure 3. Number of Articles by Research Areas.

When classifying the countries publishing articles on wearables and sports, the ranking shown in Figure 4 was obtained. The top four countries are Japan (23.48%), the People's Republic of China (20.00%), the United States (17.25%), and Australia (9.07%). When the keywords "wearable" and "sports" are excluded from the obtained articles' keywords, and a network is created using the VOSviewer program, the resulting graph is shown in Figure 5. According to this graph, the main keywords are the Inertial Measurement Unit (IMU) and its sub-component accelerometer. Machine learning and physical activity keywords follow. The area highlighted in red primarily focuses on athlete performance. The green cluster is primarily related to athlete health and nutrition. The blue region represents the concentration of machine learning-based studies on wearables and athletes. The yellow color encompasses studies in advanced topics such as electronic, flexible wearables, and robotics.

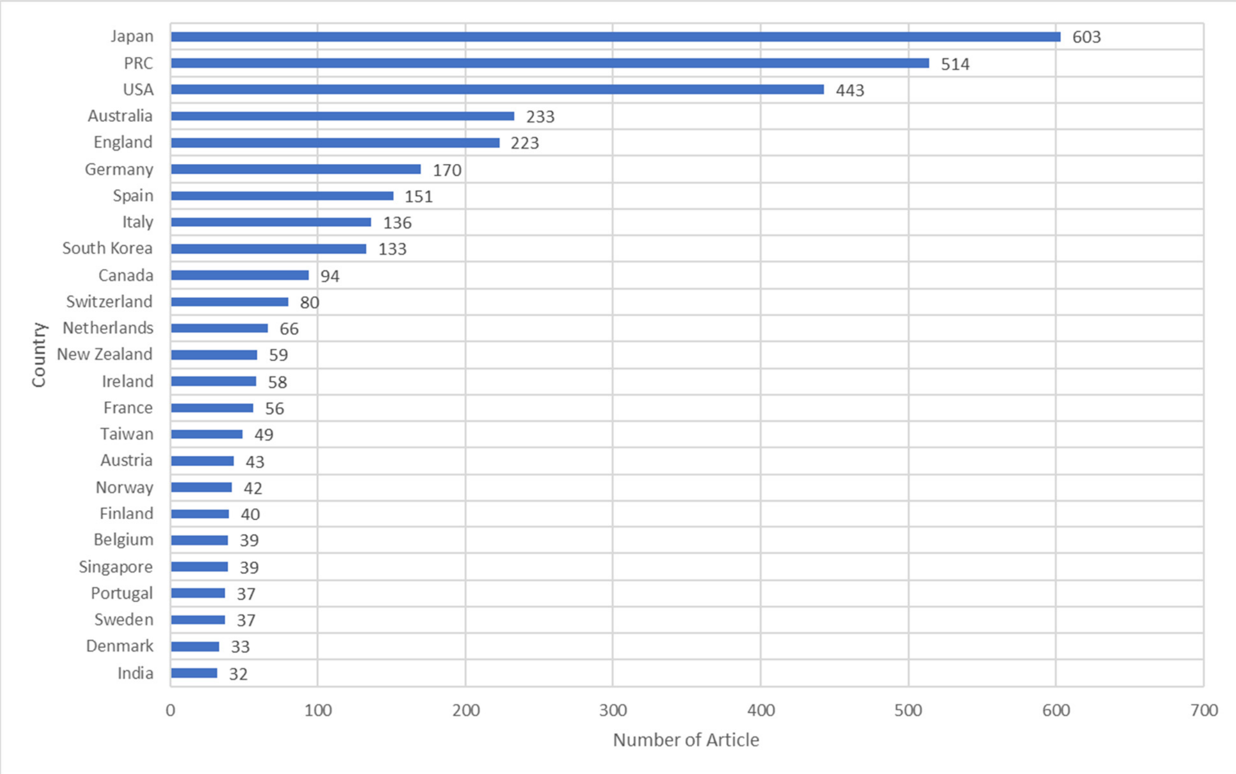

Figure 4. Number of Articles by Country.

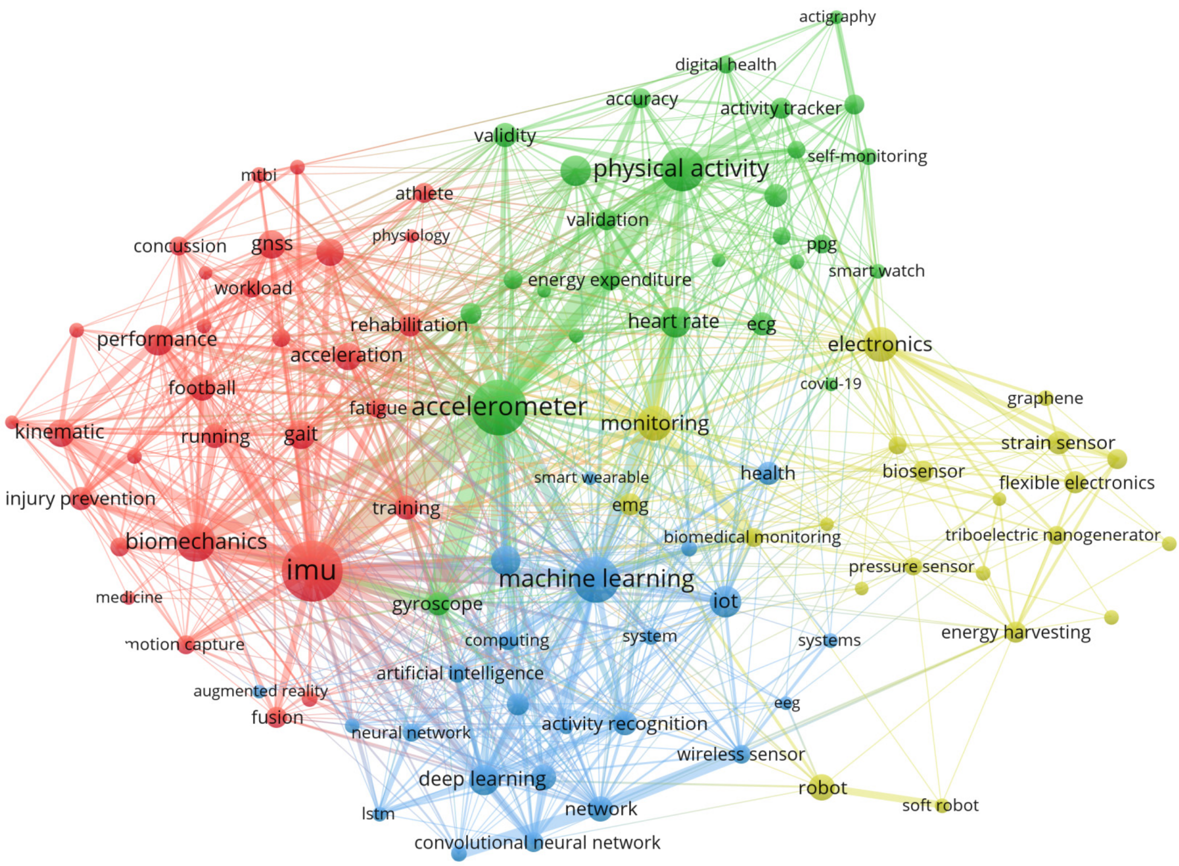

Figure 5. Keyword Co-occurrence and Cluster Network.

3. Hardware and Software of WT in Sport

WT, at its core, is Internet of Things devices and consist of three layers as illustrated in Figure 6: sensor, processing, and network. The first two layers, sensor, and processor, encompass all the operations that take place solely on the electronic hardware of the WT. Additionally, various external devices, computing methods, and communication protocols are incorporated into the network layer as part of WT.

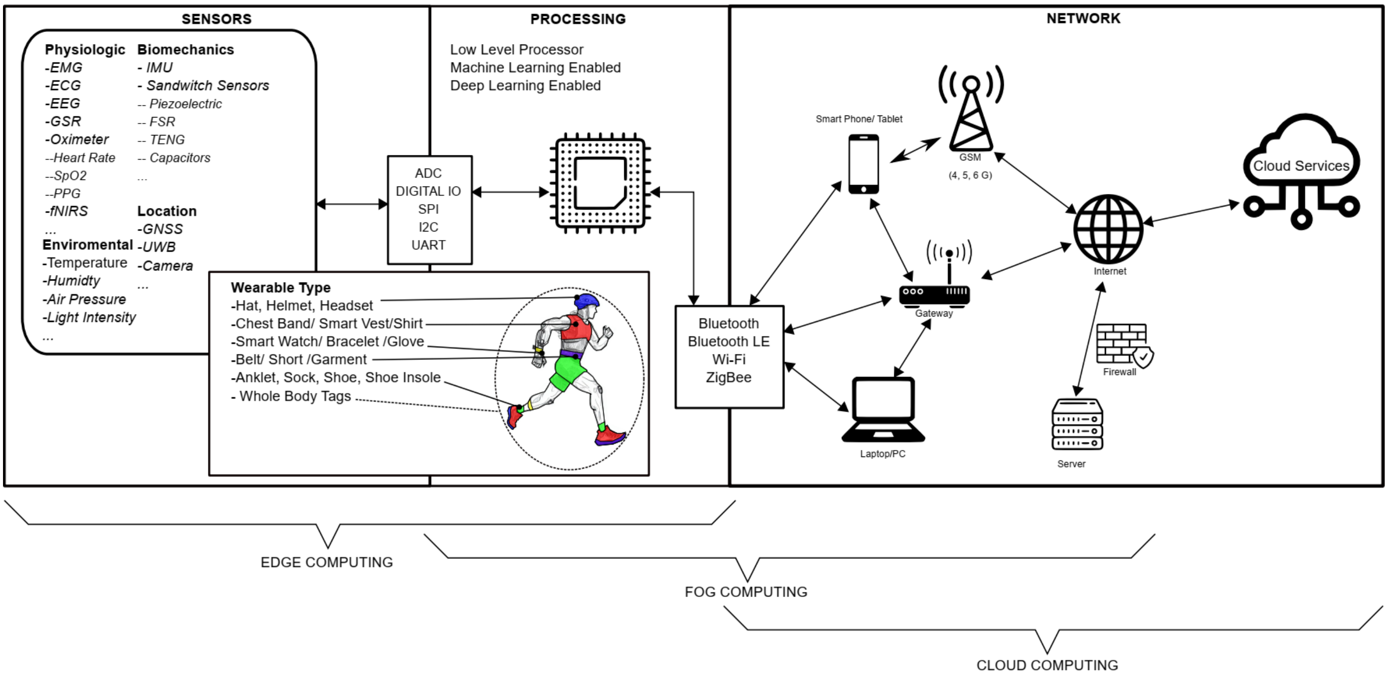

Figure 6. Layered Structure of Wearable Computing.

3.1. Sensors Layer

The first layer is the sensor layer, where information obtained from the human body through various means is transmitted as signals to the processor, the second layer of the WT, using analog-to-digital converters (ADC), digital inputs, Inter-Integrated Circuit (I2C), Universal Asynchronous Receiver/Transmitter (UART), Serial Peripheral Interface (SPI), and similar methods. In today's sports field, WT with sensors or sensor systems provides valuable data by measuring physiological, motion, position, and environmental conditions.

3.1.1. Physiological Sensors

Physiological data encompasses information derived from the biological processes occurring within the human body, serving as a valuable source of insights into an individual's health, performance, or overall condition. Prominent among the sensors used for capturing physiological data are well-recognized devices such as Electromyography (EMG), Electrocardiography (ECG), and Electroencephalography (EEG). Furthermore, physiological data acquisition extends to include an array of sensors such as functional Near-Infrared Spectroscopy (fNIRS), Oximeter, Blood Pressure Sensors (BPS), Galvanic Skin Response (GSR), and respiratory monitoring sensors.

In the context of sports and related fields, the term "biometric data" is at times used to describe the physiological data obtained from athletes [10–12]. However, it is important to distinguish this usage from the engineering domain, where "biometric data" encompasses information utilized for the purpose of identifying individuals through the analysis of their biological characteristics and events [13]. Biometric identity verification relies on immutable physical or behavioral attributes unique to each individual and is considered unalterable. Governments and security systems employ biometrics as a robust method of personal identification for this reason [14]. It is crucial to acknowledge that data gathered from sensors measuring an athlete's physiological responses do not inherently possess the same uniqueness or distinctiveness characteristic of biometric data. Consequently, caution must be exercised when applying the term "biometric data" in the context of athletic research, as this misalignment in terminology can potentially lead to legal and ethical complications, as well as cause confusion within the scientific community.

EMG system measures the electrical activity of muscles. By providing data such as muscle contractions and muscle strength, they can provide information about muscle activity and performance [15–17]. EMG electrodes are placed to detect the electrical signals originating from the muscles. During muscle contraction and relaxation, neurons in the muscle fibers produce electrical signals. This electrical activity is associated with the movement of muscles or changes in muscle tone. EMG electrodes detect and record the electrical activity of muscles by capturing this electrical activity. The obtained EMG signals are processed and recorded through amplifiers and data recorders. EMG signals reflect the magnitude, duration, timing, and coordination of muscle contractions.

ECG is a technique that records cardiac electrical activity and provides information on heart rate variability (HRV), cardiac arrhythmias, and cardiovascular health [18–20]. ECG is a valuable tool for evaluating the health and performance of athletes, as it can reflect the autonomic nervous system regulation, the metabolic demand, and the cardiac adaptation to exercise. ECG is an important tool for monitoring athletes' health and performance, optimizing exercise programs, and assessing heart health [21].ECG electrodes are placed on specific locations of the torso and limbs to capture the signals generated by the cardiac depolarization and repolarization. Some commercial WT, such as smartwatches and wristbands, claim to have ECG detection capabilities, but they usually measure a single-lead ECG that is more suitable for detecting training load or cardiac disorders than for providing a comprehensive ECG analysis [22,23]. The conventional ECG acquisition is often inconvenient and intrusive, as it requires multiple electrodes and wires that may interfere with the natural movement of the athletes.

EEG sensors measure brain waves using electrical methods and provide data related to brain activity [24,25]. These data can provide information about an athlete's brain activity, sleep quality, concentration, and other factors. The working principle of EEG involves the placement of metal plates called electrodes or sensors on the scalp. These electrodes are used to detect electrical activity in the brain. The electrodes are typically placed at specific points on the scalp to capture electrical signals from different regions of the brain. Brain cells or neurons are the cells that generate and transmit electrical signals. This electrical activity is due to the potential differences created as neurons communicate with each other. EEG electrodes detect and record these electrical activities to obtain brain wave patterns. EEG signals consist of different components known as low-frequency (slow) and high-frequency (fast) brain waves. Brain waves can reflect different aspects of brain activity such as sleep, wakefulness, focus, or different mental states [26].

Athlete brain activity monitoring applications are also measured with functional near-infrared spectroscopy (fNIRS) sensors [25,27]. Neuronal activity in the brain causes changes in oxygenation. fNIRS uses near-infrared light emitted by a light source, which is absorbed by hemoglobin in the tissue. When the oxygenation of hemoglobin changes, its absorption properties also change. When the fNIRS detector detects the reflected or scattered light from the brain, it measures the changes in oxygenation and collects this information as a data set.

Pulse oximeter sensors are used by placing them on the fingertip or near blood vessels to provide data such as peripheral oxygen saturation (SpO2), heart rate (HR), and photoplethysmography (PPG). Oximeters operate by using two different light sources: red and infrared. Oxygenated blood absorbs more red light, while deoxygenated blood absorbs more infrared light. The oximeter measures the amount of light passing through the skin or tissues using these two light sources. This data provides information about athletes' oxygen levels, heart rate, and exercise performance [28,29].

BPS facilitates the assessment of athletes' blood pressure levels and cardiovascular well-being through blood pressure measurement [30–32]. Typically, the BPS is designed as either a cuff or a wristband. This WT employs a mechanism in which the cuff is inflated using air until arterial blood flow is occluded. The pressure reading corresponding to the cessation of arterial blood flow indicates the Systolic blood pressure value. After this occlusion, the applied pressure is gradually released. During this process, oscillations in pressure occur due to cardiac contractions, and the pulse rate is determined by quantifying these oscillations and the time intervals between them. The minimal pressure threshold required for pulse detection designates the Diastolic blood pressure value. Consequently, this methodology enables the determination of both systolic (maximum) and diastolic (minimum) blood pressure values, expressed in pulse per minute and millimeters of mercury (mmHg) units.

The GSR sensor is based on the principle that the skin's electrical conductivity can vary due to sweating. Sweating increases the moisture level on the skin, thereby increasing electrical conductivity. Therefore, when a person experiences an emotional response or exerts physical effort, the amount of sweating and, consequently, the electrical conductivity change [33–35].

Respiratory sensors measure data such as respiratory rate, respiratory depth, and respiratory pattern. These data provide information about athletes' respiratory performance, exercise capacity, and energy expenditure [36–38]. These sensors typically work by measuring respiratory movements using various types of sensors, including optical, mechanical, or electromagnetic sensors, which are usually placed on the chest area. Smart masks are WT capable of monitoring an athlete's respiratory and metabolic parameters during exercises or other activities. There are many commercial examples such as Calibre [39] K5 [40], and Cortex–Metamax 3B [41]. These devices exhibit the characteristic of becoming the gold standard, particularly in terms of energy expenditure and performance measurements. Wearable smart masks comprise a multitude of sensors such as gas sensors, flow sensors, heart rate sensors, temperature sensors, and humidity sensors [42,43]. However, the primary sensors consist of oxygen and carbon dioxide gas sensors along with a flow measurement sensor. Other sensors serve auxiliary roles, and in some commercial products, they are positioned in a manner that could be more effective outside the mask, incorporating additional systems such as ECG. Wearable smart masks hold considerable potential applications within sports science and medicine. They enable accurate and continuous measurements of fundamental parameters, namely, respiratory gas exchange and metabolic rate, for evaluating aerobic capacity, anaerobic threshold, energy expenditure, substrate utilization, respiratory efficiency, lung function, and more. These parameters can aid in assessing and optimizing physical performance, including monitoring training intensity and duration, recovery, and adaptation processes, as well as identifying health issues or risks. Wearable smart masks also have the capability to offer personalized feedback and guidance tailored to users' goals and preferences.

3.1.2. Biomechanics Sensors

Biomechanics is the application of mechanical engineering principles to living organisms, and it encompasses studies at the tissue and joint levels [44]. Biomechanics involves applying forces to biological systems and specifically includes the effects of forces applied to the human body [45]. Within this scope, motion data refers to the use of sensors to monitor athletes' skeletal movements and muscle activities. In sports, the primary sensor used for motion sensing is the IMU and other sensors such as force sensors and EMG sensors are also utilized.

IMU is a type of microelectromechanical system (MEMS) sensor consisting of multiple sensors combined. An IMU sensor can include an accelerometer, gyroscope, and magnetometer sensors. The accelerometer is used to measure changes in acceleration resulting from applied forces. The gyroscope is used to determine the amount of angular rotation. The compass is used to measure the orientation of the sensor based on Earth's magnetic field.

The compass is mainly used as a supporting sensor for sensor fusion with the accelerometer and gyroscope to determine the direction and magnitude of motion [46–48]. IMU sensors can be used for various purposes such as swimming [49,50], posture analysis [51–53], and exercise tracking [54,55].

Various sensors are used for force and motion detection in the field of sports. Some of these are sandwich-type sensors consisting of piezoelectric [56–59], resistor [60–63], capacitor and magnetic elements. These sensors convert mechanical energy into electrical energy to form triboelectric nanogenerator (TENG) systems [64–66]. TENGs can be integrated with textile-based systems as wearable sensors in the field of sports [64,65]. Piezoelectric sensors are inexpensive, sensitive, and capable of measuring quickly, but piezo crystals have a fragile structure and are not suitable for highly flexing surfaces. Resistive sensors, on the other hand, measure the deformation of the tissues obtained by knitting conductive threads as a change in resistance. These sensors are affected in situations such as liquid contact and perspiration, and coated systems must be used. The Strain gauge sensor is a coated resistive sensor and must be attached to the surface to detect hand movements. These sensors are custom-made and expensive. Applications for the use of conductive liquid in silicon are resistive sensors with high performance but difficult to manufacture and design [67]. If these sensors are punctured or ruptured, the leaking liquid may harm human health. Capacitive sensors are passive circuit elements that measure the capacitance change of the dielectric material between two conductive plates. These sensors are preferred because of the insulator of biological materials and offer new horizons in the measurement of biopotential energy in humans. Capacitive sensors do not require electrodes to contact the skin, use conductive liquid/gel, or fixation, and can measure as precisely and stable as other methods.

3.1.3. Location Sensors

Location sensors are used to track athletes' position changes and movements. The most fundamental wearable positioning systems include Global Navigation Satellite System (GNSS), Ultra-wideband (UWB) positioning systems, Wi-Fi, Bluetooth, RFID, and wearable marker positioning systems [68–70]. The most used methods among these are GNSS, UWB, and camera-based wearable marker positioning systems.

GNSS refers to satellite-based navigation systems, with the Global Positioning System (GPS) being the most widely used. A GNSS receiver receives satellite signals, analyzes the timing and location of the signals, and determines the user's position accordingly. GNSS is suitable for open-field applications, but it may not work or may be misleading in indoor environments due to signal weakening and reflections. In sports, it is used for position determination, speed and distance measurement, and activity analysis studies [69,71,72].

The UWB positioning system consists of a transmitter and one or more UWB receivers. The UWB transmitter generates short-duration pulse signals and transmits them over a wide frequency band. UWB receivers receive the signals from the UWB transmitter and analyze their arrival time, power, and frequency spectrum. Through this analysis, the position of the user wearing UWB can be determined based on the time, path, and obstacles through which the signals propagate [69,73]. UWB positioning provides high accuracy and precision and is also inexpensive and easily portable. UWB modules combined with IMUs are used for applications such as motion capture, biomechanics, and action recognition [74–76].

Camera-based wearable marker positioning systems involve tracking multiple wearable markers with multiple cameras to monitor the user's position and movements. These systems allow real-world movements to be reflected in virtual environments. While these systems are designed for positioning purposes, they are primarily used in biomechanical analysis and motion recognition due to their high precision and accuracy [77–79].

3.1.4. Environmental Condition Sensors

Environmental condition sensors on the WT are sensors that measure environmental effects such as air quality, humidity, temperature, air pressure, and UV light level [3,80,81].

These sensors are used to monitor the condition of the environment where athletes are present. Air quality sensors assess the impact of factors such as air pollution and allergens by monitoring athletes' respiratory conditions during exercise. Humidity sensors track the humidity levels in the surroundings, while temperature sensors monitor environmental temperature changes. Air pressure sensors track atmospheric pressure variations and are used for altitude calculations. UV light sensors measure athletes' exposure levels to sunlight.

3.2. Processing Layer

The processing unit in the second layer is either a microcontroller or a single-board computer/processor that can be integrated within the physical boundaries of the WT. The microcontrollers or processors in the second layer possess relatively low-level capabilities in terms of memory, processing power, and operational time. Edge computing can only be performed with the hardware up to the second layer, allowing the generation of user feedback through methods such as signal processing, feature engineering, data compression, or machine learning. Actuators such as screens, LEDs, vibration motors, and speakers on WTs enable human-computer interaction by producing responses or alerts. Up to this stage, tasks performed in WT such as heart rate monitoring, oxygen level (SpO2) measurement, and step counting are at the edge computing level and do not involve wireless communication. To handle more complex tasks, higher processing capacity is required, and access to the third and fourth layers is achieved through wireless communication.

Current wearable processing units can be classified into three different levels based on their processing capabilities, power consumption, size, and features: low-level microcontrollers, high-level or machine learning-enabled microcontrollers and single-board computers. The processing and memory capacity parameter measures the computational capability of the processing unit and memory. Processing power determines the type and complexity of tasks that can be performed by the processing unit, such as data acquisition, signal processing, and machine learning. Memory affects the storage capacity, data access speed, and power consumption of the processing unit. Power consumption is dependent on the efficiency of the electronics and the amount of processing in the device. Power consumption determines the battery life, heat dissipation, and size of the processing unit. The size parameter measures the physical dimensions of the hardware unit, and it affects the portability, wearability, and aesthetics of the processing unit.

- Low-level microcontrollers have limited processing power and memory, but are suitable for data collecting and basic signal processing tasks. They are also low-cost, low-power, and small-sized devices that can be integrated with sensors and other peripherals.
- High-level microcontrollers have more processing power and memory and can support advanced functions such as machine learning, wireless communication, and security. They are also more expensive, consume more power, and require more space than low-level microcontrollers.
- Single Board Computers (SBC) have a complete system on a single board, including a processor, memory, storage, input/output ports, and operating system. They can perform complex tasks such as image recognition, speech recognition, and natural language processing. They are also more powerful, versatile, and customizable than high-level microcontrollers. These types of processors can also support deep learning applications that require intensive computation and large datasets, but they are the most expensive, power-hungry, and bulky devices among wearable processing units, so they are not widely used.

3.3. Network Layer

Due to the power and size limitations in WTs, the processing capacity is limited, and therefore, if more complex outputs are desired, the data obtained should be included in the process with wireless communication methods such as Bluetooth, Wi-Fi, Zigbee, etc. In the third layer, WT communicates wirelessly, transmitting data to devices with higher processing capacity such as computers, smartphones, gateways, and similar devices, enabling the production of more sophisticated output. The computational operations performed at this level are called fog computing. Cloud computing is used if these devices have difficulty in performing the desired operations or if more advanced services are needed. Fog computing involves processing data from WTs at nearby gateways or cloud services with higher processing capacity. At this stage, data is transferred to cloud-based services for deeper analysis, data mining and other complex operations. Wearables for cloud computing communicate directly with servers with very high processing capacity, either stand-alone or via a smartphone, computer, or gateway device. At this stage, fog or cloud computing can be used as needed.

4. Anatomical Perspective of WT

Anatomy is the study of the structure and organization of living organisms and their parts. WT is the term for devices or materials that can be worn on the body and provide some functionality, such as sensing, computing, communication, or entertainment. The relationship between anatomy and the physical structure of WT is important for several reasons:

- It affects the comfort, fit, and usability of the WT or material.
- It influences the accuracy, reliability, and validity of the data collected by the WT or material.
- It determines the potential benefits, risks, and limitations of the WT or material for different applications and users.

Sleeves, shirts, trousers, vests, jerseys, and gloves allow real-time monitoring of various internal and external training loads related to athletes. For this purpose, WT structures are designed to be placed on different anatomical regions according to the type of training and sport. The human anatomical regions are shown in Figure 7. Some of the anatomical concepts that are relevant for WT are:

- **Anatomical regions:** The body can be divided into different regions based on location, function, or structure. For example, the head, neck, torso, arm, hand, leg, and foot are anatomical regions that can wear different devices or materials.
- **Physical movement:** The body can perform different types of movement based on the joints, muscles, and bones involved. For example, flexion, extension, abduction, adduction, rotation, and circumduction are types of movement that can affect the fit, function, and comfort of WTs or materials.
- **Perspiration-comfort:** The body can produce sweat as a way of cooling down and regulating body temperature. Sweat can affect the skin condition, moisture level, and friction of the body part that wears the device or material. For example, sweat can cause skin irritation, infection, or corrosion if not properly managed by the WT or material.
- **Ergonomics:** The body can interact with the environment and the device or material in different ways based on its posture, position, and orientation. Ergonomics is the study of how to design devices or materials that fit the human body and its activities. For example, ergonomics can improve the usability, efficiency, and safety of WTs or materials.

In the process of devising WT, it becomes imperative to consider a multitude of anatomical factors. These considerations encompass the size, shape, and relative proportions of the specific body part destined to bear the device or material. Additionally, an assessment of the range of motion, flexibility, and strength exhibited by the targeted body part assumes significance. Factors such as skin sensitivity, temperature, moisture levels, and blood flow in the chosen anatomical region warrant meticulous evaluation. Furthermore, scrutiny should extend to the location, function, and potential interplay with other adjacent body parts or organs that might be influenced by the deployment of the device or material. Lastly, an indispensable facet of this comprehensive analysis lies in recognizing and accommodating the individual preferences, needs, and expectations of the end user.

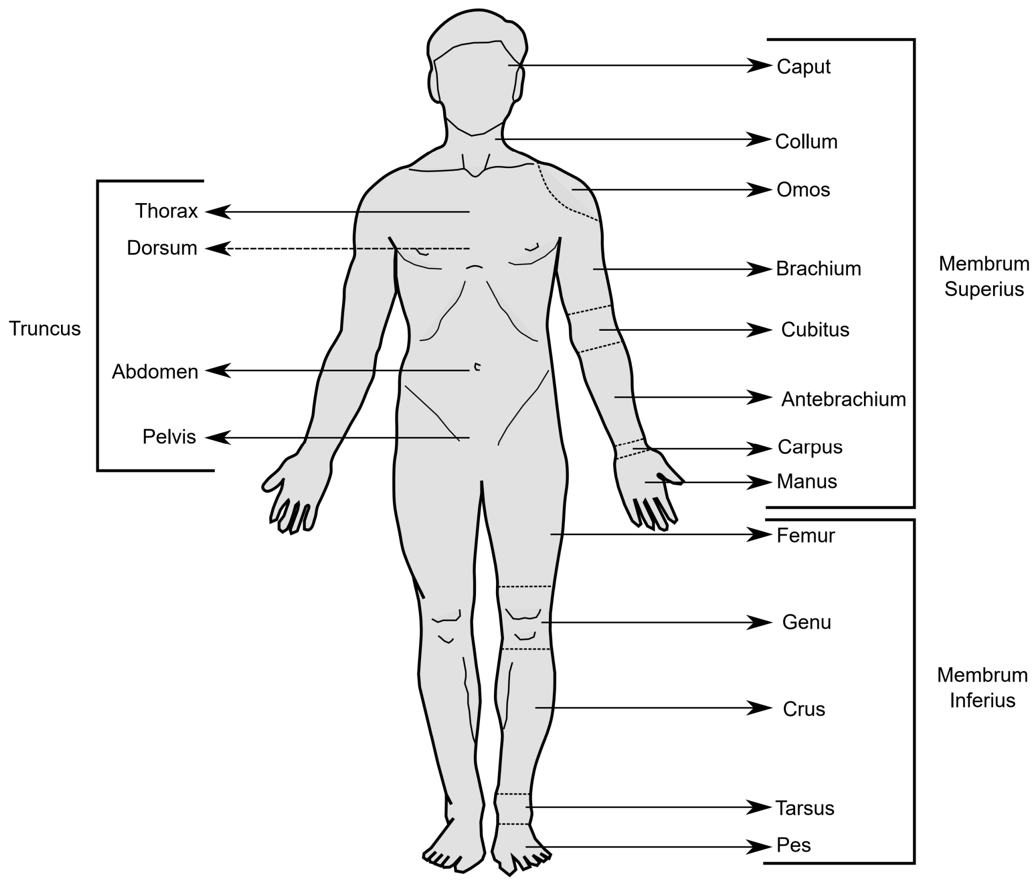

Figure 7. Anatomical parts of the human body.

The selected commercial WT devices and the anatomical regions they are worn on are presented in Table 1. Wearable technologies used in the sports field vary depending on the sport(s) and anatomical region they are used for. The main regions where commercial wearables are placed in the sports field are the thorax, brachium, antebrachium, carpus, manus, femur, crus, and caput. It is observed that these wearables are concentrated on the thorax and carpus regions in terms of anatomical regions. From this perspective, the thorax is an advantageous region for monitoring body movements due to its proximity to the physiological aspects of breathing and heart function, as well as its proximity to the body's center of gravity. The carpus, brachium, and antebrachium regions, on the other hand, are areas that can provide information about arm strength, posture angle, or the correct execution of movements in sports that heavily involve hand and arm usage. Additionally, since the veins are close to the skin in these regions, information about heart rate and oxygen levels in the blood can also be obtained.

Table 1. Commercial Wearables and Features.

Commercial WT	Anatomical Region	Sensors	Physiological	Biomechanics	Location	Environmental
Apple Watch Ultra	Carpus	GNSS, HR, SpO2, (ECG-indirect), IMU, Magnetometer, Temperature, Light, Barometer	Yes	Yes	Yes	Yes
Fitbit Charge5	Carpus	GNSS, HR, SpO2, (ECG-indirect), IMU	Yes	Yes	Yes	No
Garmin Fenix 7	Carpus	GNSS, HR, SpO2, (ECG-indirect), IMU, Magnetometer, Thermometer	Yes	Yes	Yes	Yes
Samsung Galaxy Watch Active2	Carpus	GNSS, HR, SpO2, (ECG-indirect), IMU, Barometer	Yes	Yes	Yes	Yes
WHOOPStrap4.0	Carpus	GNSS, HR, SpO2, (ECG-indirect), IMU, Magnetometer, Thermometer, GSR	Yes	Yes	Yes	Yes
Garmin Forerunner 945	Carpus	GNSS, HR, IMU, Magnetometer	Yes	Yes	Yes	No
Polar GritX	Carpus	GNSS, HR, IMU, Magnetometer	Yes	Yes	Yes	No
Suunto9	Carpus	GNSS, HR, IMU, Magnetometer	Yes	Yes	Yes	No
COROS ApexPro	Carpus	GNSS, HR, IMU, Magnetometer	Yes	Yes	Yes	No
Swimmo	Carpus	HR, IMU, Magnetometer	Yes	Yes	No	No
ZeppPlaySoccer	Carpus	GNSS, IMU, Magnetometer	Yes	Yes	Yes	No
Biostrap	Carpus	GNSS, HR, SpO2, IMU, Thermometer, GSR	Yes	Yes	Yes	Yes
CasioG-SHOCK MOVE GBD-H2000SERIES	Carpus	GNSS, HR, SpO2, IMU, Magnetometer, Thermometer, Barometer	Yes	Yes	Yes	Yes
Catapult	Dorsum	GNSS, IMU, Magnetometer	Yes	Yes	Yes	No
ViperPOD	Dorsum	GNSS, HR, IMU, Magnetometer	Yes	Yes	Yes	No
Polar Team Pro	Dorsum	GNSS, HR, IMU, Magnetometer	Yes	Yes	Yes	No
Myo Armband	Antebrachium	EMG	Yes	Yes	No	No
MotusQB	Brachium	IMU	No	Yes	No	No
Zephyr Bio Harness	Thorax	ECG, HR, Respiration Rate	Yes	No	No	No
Hexoskin	Thorax	ECG, HR, Respiration Rate	Yes	No	No	No
ZeppGolf2	Manus	GNSS, IMU, Magnetometer	No	Yes	Yes	No
Actofit Smart Ring	Manus	IMU, HR, Thermometer	Yes	No	No	Yes
KINEXON	Diverse body regions	GNSS, ECG, HR, SpO2, IMU, Magnetometer	Yes	No	Yes	No
DorsaVi Movement Suite	Diverse body regions	IMU, EMG	Yes	Yes	Yes	No
Noraxon	Diverse body regions	IMU, EMG	Yes	Yes	No	No
Xsens	Diverse body regions	GNSS, IMU, Magnetometer, Barometer	No	Yes	Yes	Yes
LumoRun	Diverse body regions	IMU	No	Yes	No	No

5. Physical Structure of Sport WT

From an anatomical perspective, the physical structure of the WT to be used varies depending on whether certain regions are mobile, semi-mobile, or fixed. The materials used in WT production in the sports field are primarily divided into three subcategories: rigid, soft, and textile-based.

5.1. Rigid Structures

Rigid WT structures are mechanically rigid systems. Many WTs in this field are designed to be rigid due to the likelihood of actions such as impacts, falls, and crushing occurring during sports activities. In rigid sensor structures, a large part of the body that makes up the sensor is primarily intended to protect the system from mechanical impacts and ensure proper attachment of the sensor in the correct position.

5.2. Soft Structures

Soft WT refers to sensor systems that can be produced by injecting conductive alloys into soft, silicone-like materials [61,82,83]. In these types, molds are prepared according to the areas where measurements will be taken, and the soft material is poured into the prepared molds. The flexibility and coating capability of soft WT allows for precise measurements. The sensor position is more stable compared to rigid WT. In soft wearable technologies, the measurement method relies on the deformation of the surface. Soft sensors are more suitable for continuous motion tracking, human-machine interfaces, and measuring physiological parameters of the human body compared to their traditional, more rigid counterparts.

5.3. Textile Structures

Textile-based WT is typically created by embedding conductors, sensors, special fibers, and other electronic components into the fabric using techniques such as weaving [82], embroidery [83–85], or knitting [86]. Among these systems, the most common and straightforward method is to add sensors to the textile surface. This can be achieved by directly sewing or gluing a typical sensor onto the fabric surface. Transmission lines required for the sensors to function are applied to the textile using conductive threads or a cable-drawing method. Another method in textile-based sensor applications is to impart sensor properties to the textile surface through various modifications [87]. These modifications can be executed internally or externally. Internal modification involves chemically or mechanically modifying the textile surface during the production of cationic yarn or fibers, making the textile surface sensitive to external factors. This way, the textile fiber or thread itself becomes a sensor. External modification refers to post-production processes such as dyeing, various coating methods, or lamination, which transform the textile surface into a sensor.

Internal and external modifications can be applied during production, but internal modifications encounter difficulties in interacting with electronic circuits and have lower sensitivity. In this regard, external modifications are more functional and practical. Internal modifications result in a more homogeneous structure since they are applied to the entire textile surface, and factors such as sliding, bending, and stretching behave uniformly across the surface. On the other hand, external modifications do not exhibit similar homogeneous behavior on the textile surface as they cause local changes [88]. Additionally, discomfort can occur more easily when there is a stiffer structure in that area when worn. Both internal and external modifications result in a change in the performance of the sensor surface when their properties deteriorate over time due to washing.

6. Overview of Commercially Available WT for Sport

The environmental condition sensors on the WT have been studied in various sports disciplines and commercial WT applications. However, in some of these studies, equipment such as Stancebeam Striker, str8bat, Zepp Baseball, Zepp Tennis 2 [3,9], Actofit Badminton Tracker, and Targetize [9] were provided as WTs. Many sources have emphasized the need for wearables to be worn on the body [2,5–7]. Therefore, in this current study, we focus only on commercially available devices that can be worn on athletes' bodies. The popular commercial wearables (n = 26) used in sports today are presented in Table 1, along with the types of sensors they contain. The selected devices and their features are summarized below. The WTs presented in Table 1 were created for informational purposes such as commercial availability, important brands, use in academic studies, or to provide examples of anatomical regions.

MotusBASEBALL (MOTUS) wearable is developed to measure various objective parameters that could be useful for monitoring, rehabilitating, and preventing injuries in baseball players. The athlete wears this sensor by inserting it into a sleeve positioned at the distal end of the throwing arm. KINEXON wearable is a widely used system in handball, football, basketball, and ice hockey. It is designed to record player position, movement, direction, and heart rate, as well as measure the physical distance and time between players. It is worn on the upper body garments of the athletes. ZEPP Golf wearable is worn on the outside of the leading arm glove and provides metrics such as club speed, hand plane, downswing, backswing, hip rotation, tempo ratio, and more. Another commonly used WT is the Catapult Sport. Catapult's WT provides real-time data on player positions (GNSS), speed, acceleration, distance, and heart rate. Its purpose is to prevent injuries during high-intensity sports by monitoring data and generating alerts about potential injuries. Clearsky T6, Optimeye S5, and Optimeye S6 are wearable products of Catapult. Viper POD is a GNSS multi-sensor-based technology used to track and analyze various data related to a player on the field. The technology can measure the energy expended by a player during training or a professional match. Viper Pod is useful not only for professional athletes and amateurs but also for sports enthusiasts. It is considered the most widely used WT in elite sports and is extensively used by top sports clubs, primarily in first-league football and basketball franchises. It provides metrics such as distance, speed, accelerations, decelerations, high metabolic load distance, dynamic stress load, and heart rate. The devices can be comfortably worn on the player's body using a belt [89]. Lumo Run is a personal running coach embedded in a small sensor that is attached to any pair of shorts (or tights). When your smartphone is nearby and your headphones are connected, it provides real-time audio feedback to correct your form, reduce the risk of injury, and hopefully help you run faster [90].

7. Applications of Wearables in Sports

The integration of WT devices into the fields of sports science and sports medicine is increasing. Nowadays, national and professional sports teams utilize WT devices to achieve general performance optimization in training and competitions [9,91], obtain quantitative biomechanical [92], and physiological [93–95] data, and monitor training load [93,96,97].

WT devices in sports include other sensors such as GNSS and IMU (accelerometers, gyroscopes, and magnetometers) [98]. These sensors provide real-time intelligent inputs that enable the measurement of various physiological characteristics, the identification of physical performance, and the characterization of biomechanical, thermal, and neuromuscular aspects of metabolic fatigue [80]. Consequently, they are seen as significant feedback mechanisms in the substantial improvement of training methods and injury prevention initiatives [99], as well as in the rehabilitation of injuries. Thus, they facilitate the development of athlete-centered training and treatment protocols, leading to enhanced athlete performance [100]. It has even been claimed that WTs are transforming the rules of sports activities [10].

With recent advancements in wearable technologies, coaches, strength and conditioning personnel, and sports scientists have shown great interest in WT for athlete tracking and performance analysis [48]. These systems allow for tracking of external training load and visualization of internal training load, enabling the application of training with targeted exercise intensity [101]. The recent amendment to World Aquatics (formerly FINA) regulations represents a significant departure from the previous stance on WTs in aquatic competitions. While the previous rules strictly prohibited any devices that could enhance swimmers' performance, the revised regulations now allow the use of technology-driven automated data collection devices, with the sole purpose of gathering data for later analysis. However, these devices are expressly forbidden from transmitting data or aiding swimmers in real-time, emphasizing their role as data-gathering tools rather than performance enhancers [102]. Many WTs are used not only in competitions but also in training, and when equipped with gyroscopes, accelerometers, and magnetometers, they allow for quantification of player load measurements. For these reasons, the use and integration of WT devices in professional sports is rapidly increasing [103].

WT devices have now reached a level of usage in sports competitions and are becoming increasingly popular in various disciplines. Major League Baseball allows the use of WTs in games, enabling analysis of various discomforts (such as specific stresses on pitchers) prevalent among baseball players [104]. The International Federation of Association Football (FIFA) and the International Tennis Federation were among the first sports federations to allow the use of these devices in international matches [69]. FIFA, in particular, announced KINEXON as the world's first "FIFA Preferred Provider Live Player and Ball Tracking" device in 2021 [105]. WTs such as CATAPULT and KINEXON are used by some basketball teams to analyze tracking data through the use of GNSS data [106].

From a sporting performance perspective, a significant advantage of wearable systems is their ability to provide real-time feedback to athletes in a real sports environment (their natural surroundings), which is not provided by video analysis [91]. For example, different sensors with the capability of collecting data in various environments are used in sports such as skiing [107], snowboarding [108], and swimming [56]. These devices have also provided tools to measure athletes' movement quantity and quality outside of a biomechanics laboratory [51].

WT devices have become indispensable assistants for coaches working to enhance sports performance [101]. The measurement and monitoring of performance and various metric data in different sports (such as football, basketball, handball, volleyball, golf, rugby, hockey, etc.) at different levels, as well as injury prevention, rehabilitation, and performance tracking, are extensively discussed in the literature (see Tables 2–4). Considering the prevalence of these devices in the articles, it can be said that the measurements obtained from these devices reflect the activities being performed.

7.1. Team Sports

Team sports are sports in which two or more opposing teams face each other. WT plays an important role in team sports to monitor the performance of players and teams, improve tactics and prevent injuries. In team sports, the functioning or harmony of the team as a group is monitored as well as the individual situations of the athletes, therefore positioning sensors are frequently used. Some sample studies for team sports are summarized in Table 2.

The Local Positioning System (LPS) (Kinexon) was used by the European Handball Federation in the Champions League Final Four (VELUX EHF FINAL4) to identify the field-based demands of a total of 40 handball players and their specific demands based on player position during both offensive and defensive plays [109]. WT was placed between the player's shoulder blades using a pouch sewn onto the player's jersey. As a result, it was reported that there were differences in player positions during both offensive and defensive plays, and considering these differences in designing training programs would positively impact individual and team performance.

Kinexon was used to simplify the external load measurements obtained from IMU data through Principal Component Analysis (PCA) and to determine if the PCA results were sensitive to load demands based on different player positions [110]. Ten male college basketball players were included in the study throughout a competition season. Prior to the matches, IMUs were placed in a sleeve sewn onto the shorts and positioned on the right posterior superior iliac spine for each player. The analyzed data set only included the external load data obtained during active playing minutes, including total mechanical loads (totMECH; a.u.), jump loads (totJUMP; J), accelerations (totACC; count), decelerations (totDEC; count), average speed (avgSPD; mph), and maximum speed (maxSPD; mph). The output values of the study indicated that, as suggested by the authors, maxSPD, totDEC, totJUMP, and totMECH were the most sensitive to positional differences and best characterized the demands of the matches.

Nunes et al. used 2 IMU sensors attached to the gastrocnemius muscles of the athletes and GNSS (ZEPP Play Soccer) to analyze both internal and external training loads and tactical actions during small-sided games (20 × 15 m, 25 × 20 m, and 30 × 25 m) [97]. Zepp's computer software V4.8.0 was used to calculate external training loads (total distance covered (m), walking (≤9 km/h), jogging (9–18 km/h), high-speed running (>18 km/h), sprint count, maximum sprint speed (km/h)) and tactical assessments (number of passes with dominant and non-dominant foot (ball touches) and maximum pass speed (km/h)). The output values of the study demonstrated that in U23 soccer players, larger playing areas with more players involved resulted in higher intensity runs, while in the same area with fewer players, more tactical individual actions were performed. Additionally, it was noted that smaller playing areas reduced the game speed in low-player systems.

Medeiros et al. demonstrated the differences between training and match physical demands in beach volleyball players using an elastic harness placed between the shoulder blades and a GNSS device (Vector-Catapult) worn under their playing attire [111]. During official matches, the players' playing time, PlayerLoadTM, total jumps, total distance covered, and the number of direction changes performed in the right and left directions were evaluated during the warm-up section, training, and technical-tactical sessions. Regardless of player position (defense or block), the players showed higher activity values during official matches compared to warm-up and training sessions. Tactical-technical training sessions exhibited higher values for all variables compared to official matches, except for the total jumps performed by the blocker.

Table 2. Wearables in Team Sports.

Ref.	Commercial Wearable	Participants Age (Year)	Performance Metrics	Outputs/Conclusion
[109]	KINEXON	40 elite handball players (29.7 ± 4.9)	Time on court, total distance, high-speed distance	Differences have been observed in terms of playing time and distances covered by athletes based on their player positions.
[110]	KINEXON	10 men NCAA DI Basketball players (NA)	Total mechanical load, jump load, accelerations, deceleration, average speed, maximum speed.	During a basketball match, it has been reported that maximum speed, decelerations, total jumps, and tot-MECH vary according to player positions.
[112]	ZEPP PLAY SOCCER	20 university-level soccer players (22.3 ± 2)	Walking, running, sprinting, maximum speed, max passing speed, passing number, dominant and non-dominant foot.	Players' physical and tactical behaviors have varied depending on the number of players during Small-Sided Games (SSGs). When played with more players (e.g., 4v6), a greater distance is covered, whereas in the opposite scenario (e.g., 4v2), an increase in walking distance has been observed.
[93]	CATAPULT	Twenty-five professional male basketball players (26.2 ± 4.9)	PlayerLoad, PlayerLoad per minute, RPE, HR	It has been stated that due to the lack of a significant relationship between weekly fluctuations in testosterone and cortisol and external and internal loads, external and internal load measurements cannot be used to predict weekly hormonal responses during the pre-season period.
[111]	CATAPULT	One defender (24) one blocker (25) beach volleyball players	Field time, PlayerLoad, total jumps, total distance, number of CODs to the right and left.	In terms of external load, it has been reported that tactical-technical training, official matches, match warm-ups, and physical training occur in that order. Additionally, differences in external load have been observed between defensive and blocking players during official matches and training sessions.
[113]	CATAPULT	36 football player (24 ± 5.26)	Distance, meters, speed, number of sprints, PlayerLoad, field time, accelerations, decelerations	It has been emphasized that all developed models can be used to predict injury risk and provide warnings about incorrect training loads.
[114]	POLAR TEAM PRO	23 top-level female football player (27.65 ± 4.66)	Walking, running, jogging, and sprinting distance, accelerations, decelerations	When considering all examined variables in a total of 23 matches, a decrease in external locomotor demand towards loads has been detected.
[115]	STATSPORTS APEX	24 semiprofessional rugby league players (25.1 ± 3.8)	Total distance, speed, maximum velocity, the number of high-intensity accelerations, dynamic stress load, high metabolic load distance.	When comparing real-time acquired data with post-event data across all analyzed parameters, a close-to-perfect or near-perfect relationship has been identified.
[116]	STATSPORTS APEX	37 elite Gaelic football players (26 ± 4)	Distance, high metabolic load distance, maximal velocity, accelerations, decelerations, dynamic stress load	No significant impact of Readiness to Train (RTT) on high-speed running performance has been detected in training and match environments.

Table 2. *Cont.*

Ref.	Commercial Wearable	Participants Age (Year)	Performance Metrics	Outputs/Conclusion
[117]	XSENS	24 highly talented female football players (14.9 ± 0.9)	Lower-limb joint kinematics (knee, hip, ankle, and pelvis)	It has been concluded that laboratory-based injury risk screening lacks ecological validity.
[118]	XSENS	27 Croatian national handball team players (16.77 ± 1.1)	Hand velocity, hand height reached, jump height, shoulder velocity, accuracy of the shot, and ball velocity/shot speed.	Significant differences have been identified in terms of all measured kinematic metrics between players' one-step and three-step jump shots.
[119]	NORAXON	Healthy male physical education students (21.2 ± 1.3)	Hip and knee joint kinematics during jumps	Participants with greater knee valgus exhibited lower gluteus medius activity, and it was found that the magnitude of pelvic tilt during UL-CMJ was not related to erector spinae or quadratus lumborum activation.

7.2. Swing Sports

Swing sport is generally defined as a category that includes sports such as golf, tennis, hockey or baseball. These sports require a person or team to swing and control the ball or racket in a specific way. WT uses it to analyze the movements of players in swing sports and optimize their performance. Some selected swing studies are summarized in Table 3.

In their study on high school male baseball players, Camp et al. compared marker-based motion capture with the motusBASEBALL sensor to analyze baseball throws [120]. Wearing compression sleeves with the IMU positioned on the medial elbow, they performed five fast throws. For each throw, they recorded and compared arm slot, arm speed, shoulder rotation, and elbow varus torque using the commercially available motusTHROW application. They reported that the IMU was reliable for measuring arm speed (RMSE range: 10.5–57.9 rpm; percentage difference: 1.2–6.2%) and shoulder rotation (RMSE range: 0.8–3.3; percentage difference: 0.5–1.6%). The study also highlighted the potential of IMU technology for performance monitoring, rehabilitation, and injury prevention in pitchers.

Boddy et al. validated wearable IMU technology with measurements corresponding to motion capture techniques [79]. Ten healthy collegiate or professional baseball pitchers performed five to seven fastballs followed by five to seven off-speed pitches (slider or curveball). Reflective markers and the MotusBASEBALL sensor were attached to the athletes. They reported significant correlation coefficients (r values) of 0.98 (arm slot), 0.75 (shoulder rotation), and 0.67 (arm stress) between the measurements corresponding to motion capture techniques.

Frontani et al. used a Shimmer3 sensor and ZeppGolf to analyze left knee biomechanics and differences among golfers of different skill levels [121]. The inertial sensor system was attached to the left glove of 18 right-handed golfers divided into three groups based on handicap score (professional, intermediate, and beginner). The accelerations recorded by the sensor in the five shots with the highest scores in ZeppGolf were analyzed, and it was found that professional players had the highest acceleration values.

Pedro et al. evaluated the concurrent validity of upper and lower extremity kinematic variables (joint angles of shoulder, elbow, wrist, separation angle, hip, knee, and ankle) obtained from an IMU system (Xsens MVN system) compared to an optical motion capture system (OS (Qualisys AB)) during a tennis forehand drive [122]. The study included 18 experienced (13 males and 5 females) and 11 intermediate male tennis players, and three repetitions of the forehand drive acceleration phase were assessed. The comparison between the systems during a forehand drive showed excellent coefficients of multiple correlation for most variables, except for the shoulder in the anteroposterior plane and the elbow in the axial plane.

Table 3. Wearables in Swing Sports.

Ref.	Commercial WT	Participants Age (Year)	Performance Metrics	Outputs/Conclusion
[123]	MOTUS	171 baseball Pitcher (9–12)	Medial elbow torque, arm speed, shoulder rotation	A relationship has been identified between increased medial elbow torque and ball velocity in young baseball pitchers.
[79]	MOTUS	10 collegiate/ pro-level baseball pitcher (23)	arm slot, arm speed, arm stress, and shoulder rotation	MotusBASEBALL has been mentioned as a low-cost and partial alternative that is suitable for performing a complete biomechanical capture.
[96]	KINEXON	44 ice hockey players (20.0 ± 1.4 and 21.9 ± 1.1)	Skating distance, speed and acceleration, turns, changes of direction (CoD), skating transitions	Kinexon LPS has been reported to provide reliable and accurate information for monitoring and assessing external loads on ice hockey players on the ice surface.
[124]	KINEXON	27 male varsity ice hockey player (22.1 ± 1.1)	Rating of Perceived Exertion (RPE), heart rate (HR)	Kinexon LPS has been reported to provide reliable and accurate information for monitoring and assessing external loads on ice hockey players on the ice surface.
[125]	CATAPULT OPTIMEYE S5	28 female cricket pace bowlers (24.9 ± 5.1)	Distance and velocity	There was a significant association of absolute ball velocity with maximum velocity during the delivery stride, peak resultant acceleration, run-up distance, and peak roll.
[126]	POLAR TEAM PRO	20 elite male field hockey players (21.2 ± 2.4)	Total distance, high-intensity-running distance, sprinting distance, accelerations load	It has been reported that performance parameters (total distance, high-intensity running distance, sprinting distance) are higher in matches compared to training periods.
[127]	ZEPP GOLF	20 EGA-handicap golfers (37 ± 13 years)	Cluphead speed	The results suggest that Zepp Golf 2 can only deliver accurate clubhead speeds on average across multiple shots, but not for individual shots.
[128]	ZEPP GOLF	7 intermediate to highly skilled male golfer (23.8 ± 4.5)	Cluphead speed	The magnitudes of frontal plane moments are greater than those previously reported, potentially indicating differing swing mechanics compared to this study, resulting in altered kinetics of the lower limbs during the golf swing.
[129]	THE MYO ARMBAND	6 expert male table tennis players (17.8 ± 1.2)	NA	The developed system can provide useful information for measuring the expert-novice differences in forehand loop skills.
[122]	XSENS	29 tennis players (21.8 ± 6)	Joint angles of shoulder, elbow, wrist, separation angle, hip, knee, and ankle	It can be concluded that it can provide excellent measurements for most joint angles during the forehand stroke, offering an advantage for data collection without the need for a limited calibrated area and the possibility of collecting data outdoors without pointer occlusion.

7.3. Other Sports

In this study, the other sports category was created for applications other than more specific sports such as team or swing sports. This includes various sports such as climbing, running or swimming, as presented in Table 4.

Breen et al. aimed to extract four time-resolved sensor-based biometrics from a non-invasive athletic compression shirt integrated with a climbing video [130]. Using a Hexoskin WT device, hip acceleration, respiration rate, minute ventilation, and heart rate were recorded every 1 s. The results demonstrated the feasibility of using time-dependent non-invasive sensor data, along with climbing videos, for obtaining machine learning-specific biometrics in the context of optimizing climbing performance.

WT can be used in swimming to monitor and improve swimmers' performance by providing feedback on posture, motion, speed, heart rate, and other physiological parameters. Costa et al. proposed a framework for intelligent swimming analytics using wearable sensors for stroke classification [131], Wang et al. developed a swimming motion analysis and posture recognition system using inertial sensors [132], and Wang et al. designed a motion capture system for human swimming posture reconstruction using multisensor data fusion algorithms and a human biomechanical model [133].

Ahamed et al. developed a classification model based on subject-specific changes in biomechanical gait patterns recorded with Lumo Run to classify changes in recreational runners' biomechanics in non-laboratory settings [52]. Pelvic drop, vertical oscillation of the pelvis, ground contact time, braking, pelvic rotation, and cadence were recorded under two different environmental conditions: winter running (mid-February to mid-March) and spring running (end of April to mid-May). The findings of the study supported the classification of subject-specific gait pattern changes based on weather conditions with an accuracy of over 80% and highlighted the importance of variable ranking in subject-specific machine-learning models.

Hu et al. conducted a randomized, placebo-controlled 8-week crossover study in novice runners [134]. The study aimed to determine the effects of graduated compression garments worn after training on recovery using daily heart rate variability (HRV) measures. Throughout the study, successive RR-interval differences and HRVs of all runners were monitored using a physiological monitor worn on the wrist (Biostrap). The results suggested that the use of graduated compression garments after training could be beneficial in mitigating some adverse effects of excessive exercise by attenuating the impact on vagally-mediated HRV.

Beanland et al., evaluated the validity of a GNSS device (Catapult) to measure swimming kinematic variables [49]. The study involved 12 male and 9 female high-level swimmers who completed three 100 m efforts in butterfly, breaststroke, and freestyle. The mid-pool swimming velocity and stroke count obtained from a digital video recording synchronized with a GNSS device (minimax S4, Catapult) equipped with a tri-axial accelerometer were compared with the velocity and stroke count data derived from the video analysis. The validity of the integrated accelerometer and GNSS device was established for stroke count measurement in breaststroke and butterfly styles and for mid-pool swimming velocity in freestyle and breaststroke styles.

Skallerud et al. examined the relationship between low back pain (LBP) and lumbar lordosis in functional dance positions (standing with feet parallel, first position, grand plié in second position, *cambré, retiré* from fifth position, *développé à la seconde*, and first arabesque) in twenty-eight female and two male collegiate dancers [135]. The study also investigated the associations of hip passive range of motion (PROM) and core stability with LBP. Wearable motion sensors (dorsaVi Kew) were used for measuring lumbar lordosis. The study findings revealed that dancers in the pain group (participants reporting pain with a score of 2 or higher on a scale of 10) exhibited higher average lordosis in each evaluated position compared to dancers without back pain (participants rating their pain below 2 on a scale of 10). However, this trend was statistically significant only in the right *retiré* and right *développé* positions. Consequently, measuring lumbar lordosis in functional dance positions, particularly in single-leg stances, could be useful for identifying dancers at high risk of experiencing low back pain.

Table 4. Wearables in Other Sports.

Ref.	Commercial Wearable	Participants Age (Years)	Performance Metrics	Outputs/Conclusion
[130]	HEXOSKIN	1 climber (NA)	Breathing rate, minute ventilation, heart rate and hip acceleration	The feasibility of using time-dependent non-invasive sensor data along with climbing videos to identify machine learning-specific biometrics in order to develop and evaluate strategies for improving climbing performance.
[52]	LUMO RUN	5 female runners (47.5 ± 9.69) one male runner (29)	Pelvic drop, vertical oscillation of pelvis, ground contact time, braking, pelvic rotation, cadence	Random forest approach has been reported as a robust method for accurately classifying large datasets collected using wearable sensors in real-world settings.
[134]	BIOSTRAP	10 novice male runners (21.5 ± 1.4)	successive RR-interval differences Heart Rate Variability	It has been suggested that the use of graduated compression garments after training can be beneficial in mitigating the effects of excessive exercise on vagally-mediated heart rate variability (HRV) and eliminating some of the harmful effects associated with overtraining.
[49]	MINIMAX S4, CATAPULT	12 male high-level swimming (15 ± 3)	Velocity, acceleration, horizontal dilution of precision	The validity of an integrated accelerometer and GNSS device has been determined for measuring stroke count in breaststroke and butterfly styles, and for measuring mid-pool swimming velocity in freestyle and breaststroke styles..
[135]	DORSAVI	28 female, 2 male collegiate dancers (18–22)	Lumbar lordosis	In dancers, measuring lumbar lordosis in functional dance positions, particularly during single-leg stance, can be useful for assessing the risk of high back pain.

7.4. Measurement and Monitoring of Athletic Performance

The performance of an athlete depends on their technical, tactical, physiological, and psychological/social characteristics. To design an effective training program, it is important to be aware of the physical demands of the sport, the athlete's capacity that can be determined through various tests, and the different components of conditioning training [136]. Proper training programs can enhance athlete performance and reduce the risk of injuries. Therefore, monitoring both training and competition loads is important in making more objective decisions when designing training programs, reducing the risk of injury for athletes, and improving their performance [137].

Considering the relationship between injuries and performance in athletes, monitoring athletes is a crucial element in sports that require high performance. There are various monitoring tools available to track an athlete's training load, their response to that load, and their relative fitness or fatigue status [138]. By collecting data from athletes, it is possible to identify their strengths and weaknesses and monitor progress toward improving performance or providing information for proper training programs. However, there are challenges in measuring training load, especially in quickly assessing a large number of athletes in laboratory settings, and providing coaches with the necessary information for the development of athletic performance [139]. For these reasons, sports teams have recently started using wearable sensors to provide a measurable indicator of the "workload" of athletes [140]. In the context of sports training, training load is defined as the manipulated input variable to elicit the desired training response [141]. Relative biological (both physiological and psychological) stressors experienced by an athlete during training or competition, such as cardiac load, blood lactate, oxygen consumption, and perceived exertion levels (RPE), are defined as internal training loads [137]. Tracking changes in internal load is used to optimize training load management and determine training adaptations. Metrics that objectively measure the work performed by an athlete during training or competition and are evaluated independently of internal loads (e.g., speed, distance covered, body load, acceleration, metabolic power, shots taken, or interventions made) are defined as external training loads [137]. The accumulation of training stress and resulting fatigue without adequate recovery can increase the risk of an unfavorable training response and injuries in players. Therefore, monitoring training loads allows coaches and clinicians to assess fatigue and physical demands in real-time, reduce the risk of injury, and optimize performance. For example, WTs incorporating GNSS and triaxial accelerometers can be used to track real-time external training load in athletes. The total running distance and intensity of sprints or collisions can be determined using GNSS sensors [100]. Studies have shown that GNSS data is used in sports such as team sports (Australian Football, Rugby, National Football League, National Hockey League) [142] and swimming [49] to integrate the physical capacity of athletes with game-specific skills, tactics, or strategic information, as well as for injury prevention.

Today, WTs designed to measure performance metrics have become accessible throughout the sports community. Monitoring an athlete's training load is seen as important by many to determine their adherence to the training program and minimize the risk of non-functional overreaching (weeks to months of fatigue), injury, and illness [143]. Therefore, monitoring training and competition loads regularly is essential for athletes to achieve optimal athletic performance.

Sports teams have a long history of using data to evaluate players. Today, advanced devices equipped with sensors can be worn by players to directly collect data [144]. Measuring and monitoring performance and physiological data often involve various measurements such as acceleration, angular velocity, temperature, heart rate, etc. [56]. Instead of monitoring a player's in-game performance, these devices measure the player's bodily performance during the game. The term physiological data in sports has a broad definition that refers to the measurement and monitoring of physical and physiological characteristics [11]. Examples of WTs that collect physiological data include heart rate and sleep monitors, as well as devices that can wirelessly collect electroencephalogram (EEG) and electrocardiogram

(ECG) data [145]. Commercially available wearable sensors worn on the body, such as the motusBASEBALL used in baseball, the KINEXON Precision Technologies sensor used in sports such as handball, football, basketball, and ice hockey, and Catapult systems (including different versions such as OptymEye, Catapult ClearSky T6), are used to obtain biometric data from athletes.

Physiological data enables the tracking of physical and physiological information for assessing performance and recovery in sports [146]. It provides more objective measurements than subjective self-reporting [145]. Professional and amateur organizations use WTs that measure physiological data, such as heart rate and body temperature, to gain a competitive advantage [147]. Osborne [148], noted that professional sports teams commonly use athlete physiological data to monitor player health, fitness, and performance; understand player load; educate coaches (and players) about the effects of training on players; and design appropriate training and rest intervals. Furthermore, the collected data can be used to improve players, prevent injuries, monitor progress, and optimize performance through injury rehabilitation.

Teams that physiological data obtained from WTs will significantly impact athletic performance, create competitive advantages, enhance fan experience, and generate new revenue streams [103]. For example, the International Tennis Federation is one of the first sports federations to allow players to wear sensors on their bodies and review critical information during set breaks [149]. Major League Baseball is also one of the first sports leagues to approve wearable physiological devices for use during games [150].

7.5. Injury Prevention

It has been reported that injury prevention is an important component of training that coaches cannot measure [151]. WT in sports is not only used for performance tracking or improvement but also for determining and preventing athlete injury incidence [151–154]. By providing real-time physiological data to athletes and coaches (compared to laboratory-based standard evaluations), WT allows for the development of accurate treatment plans and customized training programs to potentially reduce and mitigate injuries [155–157].

For example, wearable inertial sensors applied to the arm have been shown to classify shoulder joint movements with reasonable accuracy in volleyball and baseball, where injuries due to excessive use of the upper extremities are common [158]. The new generation Zepp Golf has a new Smart Coach training system [9]. The Zepp golf version provides athletes with information on the correct application of movements to minimize the risk of injury [3]. It has been reported that data obtained from IMUs can be extremely valuable in guiding individualized performance improvement, injury prevention and rehabilitation program design, as well as confirming progress toward achieving optimal neuromuscular function levels [99]. Sports injury is defined as the loss or abnormality of body structure or function resulting from exposure to physical energy in isolation during training or competition and is diagnosed as a medically recognized injury after examination by a clinical professional [159]. These injuries can increase the risk of long-term sequelae such as osteoarthritis, as well as a decrease in physical capacity and quality of life, not only in terms of treatment costs and time lost from sports for the injured athlete [160]. For these reasons, the prevention/prediction of sports injuries is considered one of the most critical aspects of athletic performance. For example, the International Football Federation (FIFA) accredits established centers that demonstrate expertise in medicine, education, and research in football in the diagnosis and treatment of injuries, care after injuries, and most importantly, injury prevention [161].

Injuries not only affect individual performance but also team performance negatively. "Training load" is reported as a risk factor for injury [162]. It has been noted that monitoring training loads for injury risk, training adaptations, and optimal performance is important by Camp et al. [163], and that there is a relationship between workload and injury rates according to Ward et al. [164], with very high player loads significantly increasing the risk of injury on a given training day. It has also been shown that biomechanical changes resulting from weak motor coordination are a risk factor for injury [152].

Any injury that can be considered a training load is generally seen as "preventable" [162]. In this context, wearable technologies can provide significant benefits to athletes, coaches, and conditioners in identifying high-risk athletes, taking necessary precautions, and rehabilitating athletes. It has been suggested that WTs can be used for managing sports injuries by facilitating the determination of the amount of relevant functional abilities before participating in high-intensity sports [151]. Ref. [152] has stated that weak motor coordination leads to hip and knee biomechanics in sport-specific dynamic movements and that monitoring motor coordination and field biomechanics with wearable sensors can be used to prevent anterior cruciate ligament injuries, which are common in team sports.

In a recent systematic study [92], research using wearable technologies covering musculoskeletal injuries in sports was examined. The articles focused on different levels of athletes (recreational active athletes, trained/developmental athletes, highly trained/national level, elite/international and first-class athletes), injured athletes, actions performed in static and dynamic tests, actions simulating injury mechanisms, or sport-specific actions in various disciplines. When the studies were analyzed in terms of sports branches, it was found that cyclic sports such as long-distance running, cross-country skiing, and cycling accounted for 43% of the studies, while team sports such as basketball, American football, soccer, Australian football, baseball, and rugby accounted for 36%. Winter and racket sports and all non-cyclic individual sports were included in the studies at similar rates (5–6%).

7.6. Optimizing Athletic Performance

In sports, success is a balance between high athletic performance and the negative consequences of excessive training and overexertion, such as severe fatigue, overuse injuries, muscle soreness, and decreased performance. Training at high volumes and intensities can be both the key to success and failure. Training volumes below what is considered optimal do not lead to adaptation, while training volumes above optimal can lead to "overtraining syndrome" [165].

Technological advancements enable athletes, coaches, and doctors to maximize performance by using wearable sensors to track functional movements, workload, biomechanics, and key physiological indicators (biovital markers) such as heart rate, blood pressure, oxygen saturation, and other relevant physiological [100,166,167]. Coaches can collect measurable data using these tools to determine which training method yields the best results [151]. The generation of large volumes of data by wearable sensors allows for the identification of patterns in athletic performance. Continuous real-time data provided before, during, and after training, as well as during activities, can be analyzed to optimize sports performance.

Liv et al. [140] indicated that WT, when used to monitor preseason and regular-season training programs, can assist team athletic training and health personnel in developing programs to optimize player performance. Studies have also indicated that wearable technologies provide independent information related to performance and can be effective tools for monitoring athlete performance. For example, PlayerLoad (Catapult) is used to identify and measure external training load with IMU. Data from additional sensors can be integrated to calculate advanced motion models and measure the load in indoor sports [168].

Due to the accessibility of wearable IMU, recent research primarily focuses on external load studies during training and/or competition. IMUs are applied in elite sports populations, particularly in indoor sports where GNSS signals are not available, to better understand movement demands [169]. IMUs allow for the examination of kinematic, technical [9], and biomechanical [3] characteristics in competitions, providing benefits for optimizing performance-related qualities such as timing, power, and speed.

8. Challenges and Opportunities

8.1. Sports Data Ethics, Privacy and Security

The integration of advanced training and preparation techniques within the sports industry heralds a transformative era, characterized by a profound emphasis on enhancing physical performance and preventing athlete injuries through the real-time provision of data. Technology is progressively becoming inseparable from the realm of sports [170]. As previously discussed, these technological advancements effectively contribute to injury prevention, performance enhancement, and the facilitation of healthy, high-level athletic careers. Consequently, real-time player performance data is systematically collected before, during, and after training sessions and competitive matches.

Nevertheless, owing to the nature of data gathered via WTs, a discernible demarcation between personal health information and other performance-related data remains elusive, accompanied by ambiguity regarding data ownership. Scholarly inquiries have spotlighted potential misuse of athlete physiological data and violations of athlete privacy [146,147]. These inquiries underscore the significant risks entailed, such as the inability to guarantee data privacy for athletes and the potential jeopardy to their careers [171]. Athlete physiological data encompasses sensitive information that is highly individualized [12] and comprises fundamental health and performance indicators [144], including medical details, as an illustrative example. It is notable that athlete physiological data may incorporate sensitive medical information that athletes would typically seek to safeguard as confidential in numerous contexts [12].

In an investigation aimed at elucidating the ownership rights pertaining to physiological data collected from professional athletes, Casher et al., assert that the entity responsible for compiling this information assumes ownership, thereby potentially engendering the perception of a player's body as a commodity owned by the team [11]. As the utilization of data beyond the sporting arena becomes increasingly normalized, this ethical quandary is poised to escalate further.

While modern athletes intelligently leverage innovative techniques facilitated by contemporary technology for training and preparation, substantial apprehension persists regarding the utilization of personal data. The incessant demand from leagues, teams, players, representatives, and media outlets for more comprehensive performance data drives the development and deployment of novel, enhanced, or simply different wearable technologies. In this context, it can be asserted that the pace of technological evolution surpasses that of legislative measures. However, these demands give rise to intricate issues concerning the collection and utilization of athletes' personal data, encompassing facets of ownership, intellectual property, privacy, and security [170]. Furthermore, the privacy, autonomy, data confidentiality, and careers of players become susceptible to risk [146].

Brown et al. conducted a comparative analysis of the protections afforded to athlete physiological data as stipulated in the collective bargaining agreements (CBAs) of the five major professional sports leagues in North America. They advocate for the applicability of federal and state laws concerning physiological data collection, drawing attention to gaps in protection and the potential vulnerability of athletes [103]. Consequently, they posit that for leagues to harness these technological opportunities, robust and uniform protection mechanisms should be implemented. Similarly, Rush and Osborne highlight significant concerns related to athlete privacy, data misuse, and exploitation, juxtaposed with the considerable potential offered by WTs for data acquisition and analysis [172].

The escalating utilization of smart devices for sports activities and physiological monitoring is unsurprising. However, despite the widespread adoption of WTs in the daily routines of both amateur and professional athletes, most sports leagues exhibit reservations regarding their in-game use [11]. This reluctance is primarily attributed to significant apprehensions surrounding cyberattacks and potential data breaches that could impact the sports industry and sports in general. In addition to the aforementioned issues, other challenges pertaining to privacy, security, and confidentiality are posed by wearable technologies in the domain of sports.

- **Data Breach and Leaks:** WTs are frequently employed for the collection and processing of personal health and performance data, encompassing details such as physical condition, location information, and other personal particulars. However, should this data fall into the hands of malicious actors or be disseminated through unauthorized access, it could lead to severe breaches of privacy, increasing the risk of misuse or undesirable utilization of users' personal and health information.
- **Data Security:** The deployment of wearable technologies introduces security vulnerabilities concerning users' health and performance data. Unauthorized access, data manipulation, or data loss could compromise data protection, thereby endangering the accuracy, integrity, and confidentiality of the information.
- **Legal and Regulatory Issues:** The integration of wearable technologies in sports engenders legal and regulatory complexities. Adherence to various legal regulations is imperative throughout the processes of data collection, processing, and sharing, particularly when handling sensitive information such as health data. Violations of these regulations may result in legal repercussions and expose companies or organizations to criminal or legal consequences.
- **Ethical Concerns:** Concurrent with the adoption of wearable technologies in sports, ethical considerations assume paramount importance. Ethical principles governing the collection, use, and dissemination of personal data should be meticulously observed to safeguard athletes' privacy, autonomy, and rights. Furthermore, equitable and unbiased utilization of these technologies is crucial, ensuring equal opportunities for all.

Addressing these issues is imperative to maintain trust among athletes, sports organizations, and technology providers. Appropriate technical safeguards, adherence to legal regulations, and the application of ethical principles should be rigorously enforced to fortify privacy, security, and confidentiality within the realm of wearable technologies in sports.

8.2. Remote and Artificial Intelligence Coaching

The integration of artificial intelligence (AI) and wearable technology has revolutionized the sports landscape, providing real-time data acquisition during training sessions and competitions. These sensors offer access to objective physiological data, enabling the measurement of internal load metrics that were once reliant on expensive and specialized equipment. This data holds immense promise in shaping targeted training programs, refining competition strategies, and even forecasting and preventing injuries for competitive athletes.

WT has ushered in a new era of data-driven sports coaching, offering coaches and athletes real-time insights into crucial physiological parameters. By leveraging WT, coaches can collect and analyze an unprecedented volume of data, facilitating the fine-tuning of training regimens and making data-informed decisions that maximize an athlete's performance potential while minimizing the risk of injury.

AI-powered coaching systems have the potential to revolutionize the way athletes receive guidance and feedback. They can analyze vast datasets generated by wearable sensors to provide real-time, data-driven insights into an athlete's performance. AI can identify trends, patterns, and anomalies in an athlete's data, offering personalized recommendations for improvement.

Coaches are responsible for the physical, psychological, and technical-tactical development of athletes, as well as monitoring their sports performance and health. Nowadays, wearable sensors provide great convenience in obtaining real-time objective physiological data during training sessions or competitions. For instance, they enable the measurement of internal load metrics that require expensive and specialized equipment. Thus, increasing the amount of available data for performance analysis presents significant potential in developing targeted training programs, competition strategies, and predicting/preventing injuries for competitive athletes. Furthermore, in the future, it is foreseeable that remote coaching systems could evolve without limitations of space and time.

Despite advancements in AI and WT, the enduring importance of human coaches in the athlete-coach relationship remains essential. The athlete-coach relationship encompasses more than data analysis; it involves mentorship, motivation, and emotional support. The synergy between human coaches and AI coaching systems holds the potential to unlock new dimensions of athlete development and performance excellence. In a recent study [173], the significance of coaches' physical, technical, tactical, and strategic abilities, as well as their subjective reflection, response to feedback, emotional and stress resilience, and neurosocial and neuropsychological aspects, has been demonstrated. Athletes rely on psychological support and verbal feedback from coaches during training sessions or competitions. It should not be forgotten that effective communication skills of coaches and verbal feedback are variables that positively impact both sports performance and social and emotional learning. For these reasons, from a sports performance perspective, it may be more accurate to say that wearable sensors can serve as assistant coaches rather than replace coaches entirely.

8.3. WT Comfort and Athlete Performance

The impact of clothing on the comfort and performance of athletes has been extensively studied. Sportswear is crucial for providing physiological comfort, which directly affects the well-being, efficiency, and performance of athletes [174]. Textile comfort, often described as the "physiological function" of sportswear, can be measured and quantified through various methods, including wearer trials and laboratory measurements [174]. These measurements ensure efficient product development and certification processes, enabling the creation of sportswear that enhances comfort and performance.

The most popular topics in comfort can be divided into two types: thermal and sensory comfort. Clothing comfort has a significant impact on athletes. Clothing comfort can be defined as the awareness of the thermal atmosphere provided by the clothes one wears, and this thermal atmosphere corresponds to a neutral sensation in a specific thermal environment without sweating [175]. Thermal comfort is a significant aspect of clothing and WT for athletes. Both rational and adaptive approaches have been employed to understand and predict thermal sensation accurately [176]. The rational approach, which considers near-sedentary activities and steady-state conditions, provides accurate predictions in controlled environments but may not fully represent actual thermal sensations experienced in the field. On the other hand, the adaptive approach allows for studying thermal comfort in everyday habitats, including real-world clothing and behaviors, and emphasizes the need for field studies in addition to laboratory experiments [176].

Thermal comfort is associated with the ability of clothing to assist in regulating the user's body temperature and managing moisture [177,178]. Thermal comfort for athletes positively influences their performance and overall well-being [178]. Thermal comfort for athletes can enhance their performance and impact their health, as it assists in regulating their body temperature and reducing fatigue [174,179,180].

Sensory comfort refers to a type of fabric or material designed to provide a pleasant and soothing tactile experience, promoting a sense of physical well-being and relaxation [181–183]. It typically incorporates softness, breathability, and hypoallergenic properties to enhance comfort for the wearer. Sensory comfort for athletes enhances their freedom of movement and increases the comfort they experience during interactions with their clothing. The desired features in clothing that significantly impact athletes' performance can vary depending on the specific sports discipline. Similarly, the desired features in WT can also differ. For example, a WT used by a swimmer needs to be waterproof, while a football player may require a WT with high resistance to friction. However, common features sought in WTs used across all sports generally include ease of movement and a close fit to the body. To enhance athletic performance and ensure athlete well-being, there is a need to increase research and development efforts in clothing comfort within both the academic and ready-to-wear sectors.

As seen in Tables 1 and 2, WT in sports often utilizes rigid and non-breathable materials made of polymers. To enhance the comfort of WT, it is expected that there will be an increase in the use of flexible, breathable, sweat-wicking, and skin-friendly textile surfaces, along with the development of sensor technologies for these surfaces.

8.4. Economy and Unfair Competition

Regardless of the sports discipline, all sports have the ability to excel under the same conditions. The concept of technological doping is a relatively new idea that refers to the advantages that can be gained by an athlete using technology. This has raised the question of 'when does a competitive advantage end and unfair advantage begin?' as a result [184]. As mentioned earlier, WT provides athletes with access to more data for performance analysis. This enables the development of more effective and tailored training programs and competition strategies to achieve peak performance during training sessions and competitions. While the use of WTs has become more widespread in the past decade, it can be argued that not all athletes have access to these devices. Furthermore, with advancing technology, the production of more advanced devices may be limited to clubs with sufficient economic resources initially. In this case, an unfair advantage may arise in the context of those who benefit from these sensors. Particularly in sports where outcomes are determined by fractions of seconds, the dimension of unfair competition can be even greater.

8.5. Personalized, High Density and Novel WT

The future prospects of WT within the realm of sports exhibit substantial potential due to advancements in personalization, heightened data density, and the seamless integration of novel sensors. Given that each athlete possesses unique anatomical and physiological attributes, the significance of tailored sizing and customized wearable designs cannot be overstated. To tackle this challenge, current viable solutions encompass the utilization of 3D printing or molding techniques for wearable fabrication, in addition to the incorporation of flexible textile materials. Augmenting data density entails the integration of a greater number of sensors or the incorporation of a broader spectrum of sensor types. Notably, encoders play an indispensable role in modeling alterations in body shape, particularly in the context of shape-based imaging devices such as Electrical Impedance Tomography (EIT). Accurate measurement of alterations in WT form directly influences the quality of images derived from these WTs.

One noteworthy technological innovation with profound implications for sports is the Triboelectric Nanogenerator (TENG) sensors. These sensors have the capacity to generate electricity through human bodily movements while concurrently collecting motion-related data. In the sports domain, TENG sensors hold the potential to monitor and enhance athletes' performance, safeguard their health, and optimize safety protocols. For instance, a shoe equipped with TENG sensors can systematically gauge a runner's step count, velocity, level of fatigue, foot pressure distribution, balance, and susceptibility to injury [185,186]. Nevertheless, challenges persist concerning the stability, longevity, and scientific applicability of TENG technology. Factors such as material selection, design enhancements, and protective measures are of paramount importance in mitigating vulnerabilities to mechanical forces. Additionally, the establishment of standardized testing methodologies and calibration protocols is imperative to account for variances in energy and data generation predicated on patterns of bodily movement, intensity levels, and frequencies. TENG technology offers invaluable contributions by serving as an autonomous energy source for WTs, thereby obviating the necessity for athletes to frequently replace or recharge batteries. Furthermore, it facilitates real-time tracking of athletes' movements, thereby facilitating performance optimization, injury prevention, and health monitoring through data analysis. Looking ahead, TENG technology is poised to garner widespread and diverse applications within the realm of sports.

In the foreseeable future, the introduction of wearable Electrode Electrical Impedance Tomography (EIT) devices or infrared tomography devices holds the potential to wield substantial influence in the domains of sports rehabilitation and imaging [187–189]. EIT is a technology that utilizes the body's electrical conduction properties to produce EIT constitutes a technology that leverages the body's electrical conduction properties to generate imaging. EIT devices are adept at detecting muscle impairments or injuries by measuring electrical conduction characteristics within the body, thereby furnishing real-time insights to athletes and coaches alike. Conversely, infrared tomography engenders imagery predicated on the emission and absorption of infrared light in the targeted region. WTs featuring imaging technologies exhibit the capacity to monitor athletes' performance in real-time and proffer efficacious rehabilitation protocols in the event of injuries [190,191]. By integrating these devices into sports rehabilitation procedures, it becomes possible to systematically monitor muscle recovery following injuries, identify muscle imbalances, and determine appropriate treatment modalities. The widespread adoption of wearable imaging devices can enable non-invasive tracking of athletes' internal physiological structures and facilitate the development of customized treatment regimens, ultimately leading to accelerated recovery and the optimization of athletic performance. Consequently, wearable imaging devices hold immense promise as invaluable tools within the domains of sports rehabilitation and performance monitoring. The development of personalized WTs for therapeutic purposes is of paramount significance, as it accounts for individual idiosyncrasies when crafting treatment protocols, ultimately benefiting both the well-being of injured athletes or professionals and the economic viability of sports as a whole.

9. Conclusions

In this present investigation, the primary objective is to provide a comprehensive bibliographic analysis encompassing the facets of sensor technology and data utilization within the realm of sports, with a specific focus on the applications of WTs in sports as documented in the extant literature. Furthermore, this study expounds upon the applications of WT within the context of sportive performance measurement, injury prevention, and the optimization of athletic performance across diverse sporting disciplines. There is an observable upward trajectory in the number of publications pertaining to WT within the domain of sports, indicative of the increasing prevalence and adoption of such technologies. Notably, the bibliographic landscape reveals a more pronounced presence of publications and research activities emanating from Eastern countries, which, relative to their Western counterparts, have exhibited disparities in both the number of athletes and sports achievements. Consequently, WT has emerged as a catalyst for various sporting objectives related to performance enhancement.

Based on an analysis of studies investigating commercial WT applications across various sports, it is evident that athletes and coaches deploy these technologies extensively for purposes encompassing performance assessment and monitoring, injury mitigation, and the optimization of athletic capabilities. This pervasive integration of WTs is not confined solely to training regimens but extends to competitive sports as well. WT technology is posited as an alternative means for the real-time acquisition of physiological and kinematic data, particularly in sports disciplines such as swimming, team sports, and skiing, where conventional camera-based tracking systems face inherent challenges. Consequently, the multifaceted and data-rich environment afforded by WT not only streamlines the roles of coaches but also engenders a more professional approach to domains including data science, health, and rehabilitation. Notably, this transformation extends its influence beyond the purview of athletes and coaches, encompassing officiating aspects such as referee training and player tracking.

Athletes, coaches, and sports scientists anticipate wearable sensors to not only enhance their utility but also provide more refined and concentrated information to facilitate performance optimization. In this context, this study aspires to contribute to the development and diversification of wearable technologies, spanning both basic and advanced iterations.

It is imperative, however, to acknowledge that the proliferation of WT introduces concerns pertaining to privacy, data security, and career ramifications, as athletes have the capability to monitor their own performance as well as that of others. In this regard, this study anticipates fostering awareness and instigating dialogue regarding the establishment of robust and effective protective measures.

The application of wearable technologies within the realm of sports holds considerable promise while simultaneously presenting an array of challenges and opportunities. The provision of real-time data offers substantial advantages in areas such as performance analysis, injury prediction, and rehabilitation. Harnessing these technologies to bolster the health, recovery, and performance of athletes can substantially expand access to advanced training and preparation techniques within the sports industry. Nevertheless, it is imperative to address sensitive issues such as equity, privacy, security, and intellectual property rights in the utilization of these technologies. The promotion of safe and equitable deployment of wearable technologies necessitates the implementation of legal frameworks, ethical principles, and appropriate technological safeguards. Additionally, further exploration into the development of personalized WT devices and their impact on athlete comfort and performance represents a valuable avenue for future research. Furthermore, the emergence of wearable imaging devices presents a promising avenue in the domains of sports rehabilitation and performance monitoring. By judiciously capitalizing on the opportunities proffered by these technologies, the sports industry can proactively support the health, recovery, and performance of athletes.

Author Contributions: Conceptualization, A.Ç.S., B.A. and M.S.; methodology, A.Ç.S., B.A. and M.S.; investigation, A.Ç.S., B.A. and M.S.; resources, A.Ç.S., B.A. and M.S.; writing—original draft preparation, A.Ç.S., B.A. and M.S.; writing—review and editing, A.Ç.S., B.A. and M.S.; visualization, A.Ç.S., B.A. and M.S.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Guler, S.D.; Gannon, M.; Sicchio, K. A Brief History of Wearables. In *Crafting Wearables: Blending Technology with Fashion*; Guler, S.D., Gannon, M., Sicchio, K., Eds.; Apress: Berkeley, CA, 2016; pp. 3–10. ISBN 978-1-4842-1808-2.
2. Godfrey, A.; Hetherington, V.; Shum, H.; Bonato, P.; Lovell, N.H.; Stuart, S. From A to Z: Wearable Technology Explained. *Maturitas* **2018**, *113*, 40–47. [CrossRef]
3. Aroganam, G.; Manivannan, N.; Harrison, D. Review on Wearable Technology Sensors Used in Consumer Sport Applications. *Sensors* **2019**, *19*, 1983. [CrossRef] [PubMed]
4. Park, S.; Jayaraman, S. Wearables: Fundamentals, Advancements, and a Roadmap for the Future. In *Wearable Sensors*, 2nd ed.; Academic Press: Oxford, UK, 2021; pp. 3–27. ISBN 978-0-12-819246-7.
5. Seçkin, M.; Seçkin, A.Ç.; Gençer, Ç. Biomedical Sensors and Applications of Wearable Technologies on Arm and Hand. *Biomed. Mater. Devices* **2022**. [CrossRef]
6. Shen, H.; Liu, T.; Qin, D.; Bo, X.; Wang, L.; Wang, F.; Yuan, Q.; Wagberg, T.; Hu, G.; Zhou, M. Chapter 7—Wearable Carbon Nanotube Devices for Sensing. In *Industrial Applications of Carbon Nanotubes*; Peng, H., Li, Q., Chen, T., Eds.; Micro and Nano Technologies; Elsevier: Boston, MA, USA, 2017; pp. 179–199. ISBN 978-0-323-41481-4.
7. Coyle, S.; Diamond, D. Medical Applications of Smart Textiles. In *Advances in Smart Medical Textiles*; Woodhead Publishing Series in Textiles; Woodhead Publishing: Oxford, 2016; pp. 215–237. ISBN 978-1-78242-379-9.
8. Ye, C.; Ren, J.; Wang, Y.; Zhang, W.; Qian, C.; Han, J.; Zhang, C.; Jin, K.; Buehler, M.J.; Kaplan, D.L.; et al. Design and Fabrication of Silk Templated Electronic Yarns and Applications in Multifunctional Textiles. *Matter* **2019**, *1*, 1411–1425. [CrossRef]
9. Rana, M.; Mittal, V. Wearable Sensors for Real-Time Kinematics Analysis in Sports: A Review. *IEEE Sens. J.* **2020**, *21*, 1187–1207. [CrossRef]
10. Nithya, N.; Nallavan, G. Role of Wearables in Sports Based on Activity Recognition and Biometric Parameters: A Survey. In Proceedings of the 2021 International Conference on Artificial Intelligence and Smart Systems (ICAIS), Coimbatore, India, 25–27 March 2021; pp. 1700–1705.
11. Casher, C. Moneyball in the Era of Biometrics: Who Has Ownership over the Biometric Data of Professional Athletes. *Dalhous. J. Leg. Stud.* **2019**, *28*, 1.
12. Garlewicz, A. Athlete Biometric Data in Soccer: Athlete Protection or Athlete Exploitation? *DePaul J. Sports Law* **2020**, *16*, ii.

13. Martin, L. Chapter 37—Biometrics. In *Computer and Information Security Handbook*; Vacca, J.R., Ed.; Morgan Kaufmann: Boston, MA, USA, 2009; pp. 645–659. ISBN 978-0-12-374354-1.
14. Shavers, B.; Bair, J. Chapter 9—Digital Identity. In *Hiding Behind the Keyboard*; Shavers, B., Bair, J., Eds.; Syngress: Boston, MA, USA, 2016; pp. 187–202. ISBN 978-0-12-803340-1.
15. Ahsan, M.R.; Ibrahimy, M.I.; Khalifa, O.O. EMG Signal Classification for Human Computer Interaction: A Review. *Eur. J. Sci. Res.* **2009**, *33*, 480–501.
16. Clarys, J.P.; Cabri, J. Electromyography and the Study of Sports Movements: A Review. *J. Sports Sci.* **1993**, *11*, 379–448. [CrossRef]
17. Taborri, J.; Keogh, J.; Kos, A.; Santuz, A.; Umek, A.; Urbanczyk, C.; van der Kruk, E.; Rossi, S. Sport Biomechanics Applications Using Inertial, Force, and EMG Sensors: A Literature Overview. *Appl. Bionics Biomech.* **2020**, *2020*, e2041549. [CrossRef]
18. Machado Leite, S.; Freitas, J.; Campelo, M.; Maciel, M.J. Electrocardiographic Evaluation in Athletes: 'Normal' Changes in the Athlete's Heart and Benefits and Disadvantages of Screening. *Rev. Port. Cardiol.* **2016**, *35*, 169–177. [CrossRef]
19. Sarubbi, B.; Papaccioli, G.; Ciriello, G.D.; Russo, V.; Correra, A.; Baggish, A. Chapter 3—Electrocardiogram in Athletes. In *Athlete' s Heart*; D'Andrea, A., Bossone, E., Eds.; Academic Press: Cambridge, MA, USA, 2023; pp. 51–76. ISBN 978-0-323-95221-7.
20. Romagnoli, S.; Ripanti, F.; Morettini, M.; Burattini, L.; Sbrollini, A. Wearable and Portable Devices for Acquisition of Cardiac Signals While Practicing Sport: A Scoping Review. *Sensors* **2023**, *23*, 3350. [CrossRef] [PubMed]
21. Löllgen, H.; Leyk, D. Exercise Testing in Sports Medicine. *Dtsch. Ärztebl. Int.* **2018**, *115*, 409. [CrossRef]
22. Isakadze, N.; Martin, S.S. How Useful Is the Smartwatch ECG? *Trends Cardiovasc. Med.* **2020**, *30*, 442–448. [CrossRef] [PubMed]
23. Sarhaddi, F.; Kazemi, K.; Azimi, I.; Cao, R.; Niela-Vilén, H.; Axelin, A.; Liljeberg, P.; Rahmani, A.M. A Comprehensive Accuracy Assessment of Samsung Smartwatch Heart Rate and Heart Rate Variability. *PLoS ONE* **2022**, *17*, e0268361. [CrossRef]
24. Thompson, T.; Steffert, T.; Ros, T.; Leach, J.; Gruzelier, J. EEG Applications for Sport and Performance. *Methods* **2008**, *45*, 279–288. [CrossRef]
25. Perrey, S.; Besson, P. Chapter 14—Studying Brain Activity in Sports Performance: Contributions and Issues. In *Progress in Brain Research*; Marcora, S., Sarkar, M., Eds.; Sport and the Brain: The Science of Preparing, Enduring and Winning, Part C; Elsevier: Amsterdam, The Netherlands, 2018; Volume 240, pp. 247–267.
26. Casson, A.J. Wearable EEG and Beyond. *Biomed. Eng. Lett.* **2019**, *9*, 53–71. [CrossRef]
27. Chen, Y.; Lu, Y.; Zhou, C.; Wang, X. The Effects of Aerobic Exercise on Working Memory in Methamphetamine-Dependent Patients: Evidence from Combined fNIRS and ERP. *Psychol. Sport Exerc.* **2020**, *49*, 101685. [CrossRef]
28. Fu, Y.; Liu, J. System Design for Wearable Blood Oxygen Saturation and Pulse Measurement Device. *Procedia Manuf.* **2015**, *3*, 1187–1194. [CrossRef]
29. Seçkin, A.Ç. Multi-Sensor Glove Design and Bio-Signal Data Collection. *Nat. Appl. Sci. J.* **2021**, *3*, 87–93.
30. Xin, Q.; Wu, J. A Novel Wearable Device for Continuous, Non-Invasion Blood Pressure Measurement. *Comput. Biol. Chem.* **2017**, *69*, 134–137. [CrossRef] [PubMed]
31. Ray, T.; Choi, J.; Reeder, J.; Lee, S.P.; Aranyosi, A.J.; Ghaffari, R.; Rogers, J.A. Soft, Skin-Interfaced Wearable Systems for Sports Science and Analytics. *Curr. Opin. Biomed. Eng.* **2019**, *9*, 47–56. [CrossRef]
32. Li, L.; Li, Y.; Yang, L.; Fang, F.; Yan, Z.; Sun, Q. Continuous and Accurate Blood Pressure Monitoring Based on Wearable Optical Fiber Wristband. *IEEE Sens. J.* **2021**, *21*, 3049–3057. [CrossRef]
33. Oweis, K.; Quteishat, H.; Zgoul, M.; Haddad, A. A Study on the Effect of Sports on Academic Stress Using Wearable Galvanic Skin Response. In Proceedings of the 2018 12th International Symposium on Medical Information and Communication Technology (ISMICT), Sydney, NSW, Australia, 26–28 March 2018; pp. 1–6.
34. Shu, Y.-S.; Chen, Z.-X.; Lin, Y.-H.; Wu, S.-H.; Huang, W.-H.; Chiou, A.Y.-C.; Huang, C.-Y.; Hsieh, H.-Y.; Liao, F.-W.; Zou, T.-F. 26.1 A 4.5 Mm 2 Multimodal Biosensing SoC for PPG, ECG, BIOZ and GSR Acquisition in Consumer Wearable Devices. In Proceedings of the 2020 IEEE International Solid-State Circuits Conference-(ISSCC), San Francisco, CA, USA, 16–20 February 2020; pp. 400–402.
35. Liaqat, S.; Dashtipour, K.; Rizwan, A.; Usman, M.; Shah, S.A.; Arshad, K.; Assaleh, K.; Ramzan, N. Personalized Wearable Electrodermal Sensing-Based Human Skin Hydration Level Detection for Sports, Health and Wellbeing. *Sci. Rep.* **2022**, *12*, 3715. [CrossRef] [PubMed]
36. Vanegas, E.; Igual, R.; Plaza, I. Sensing Systems for Respiration Monitoring: A Technical Systematic Review. *Sensors* **2020**, *20*, 5446. [CrossRef] [PubMed]
37. De Fazio, R.; Stabile, M.; De Vittorio, M.; Velázquez, R.; Visconti, P. An Overview of Wearable Piezoresistive and Inertial Sensors for Respiration Rate Monitoring. *Electronics* **2021**, *10*, 2178. [CrossRef]
38. Bernhart, S.; Harbour, E.; Jensen, U.; Finkenzeller, T. Wearable Chest Sensor for Running Stride and Respiration Detection. *Sports Eng.* **2022**, *26*, 19. [CrossRef]
39. Biometrics, C. Unlock the Data in Your Breath! Available online: https://calibrebio.com/ (accessed on 30 August 2023).
40. COSMED—K5: Wearable Metabolic System for Both Laboratory and Field Testing. Available online: https://www.cosmed.com/en/products/cardio-pulmonary-exercise-test/k5 (accessed on 30 August 2023).
41. METAMAX 3B. Available online: https://cortex-medical.com/EN/METAMAX-3B-en.htm (accessed on 30 August 2023).
42. Macfarlane, D.J. Open-Circuit Respirometry: A Historical Review of Portable Gas Analysis Systems. *Eur. J. Appl. Physiol.* **2017**, *117*, 2369–2386. [CrossRef]

43. Escobedo, P.; Fernández-Ramos, M.D.; López-Ruiz, N.; Moyano-Rodríguez, O.; Martínez-Olmos, A.; Pérez de Vargas-Sansalvador, I.M.; Carvajal, M.A.; Capitán-Vallvey, L.F.; Palma, A.J. Smart Facemask for Wireless CO_2 Monitoring. *Nat. Commun.* **2022**, *13*, 72. [CrossRef]
44. Koff, M.F. 9—Biomechanics of Peripheral Joints. In *Rheumatology*, 6th ed.; Hochberg, M.C., Silman, A.J., Smolen, J.S., Weinblatt, M.E., Weisman, M.H., Eds.; Mosby: Philadelphia, 2015; pp. 65–71. ISBN 978-0-323-09138-1.
45. Howell, J. 12—Principles and Components of Upper Limb Orthoses. In *Atlas of Orthoses and Assistive Devices*, 5th ed.; Webster, J.B., Murphy, D.P., Eds.; Elsevier: Philadelphia, PA, USA, 2019; pp. 134–145.e1. ISBN 978-0-323-48323-0.
46. Fonseca, J.; Ramos, V.; Amaro, J.P.; Moita, F.; Roseiro, L. Framework for Knee Joint Movement Analysis with Inertial Sensors and Recursive Filters. In Proceedings of the 2019 IEEE 6th Portuguese Meeting on Bioengineering (ENBENG), Lisbon, Portugal, 22–23 February 2019; pp. 1–4.
47. Wilk, M.P.; Walsh, M.; O'Flynn, B. Multimodal Sensor Fusion for Low-Power Wearable Human Motion Tracking Systems in Sports Applications. *IEEE Sens. J.* **2020**, *21*, 5195–5212. [CrossRef]
48. Waqar, A.; Ahmad, I.; Habibi, D.; Hart, N.; Phung, Q.V. Enhancing Athlete Tracking Using Data Fusion in Wearable Technologies. *IEEE Trans. Instrum. Meas.* **2021**, *70*, 4004013. [CrossRef]
49. Beanland, E.; Main, L.C.; Aisbett, B.; Gastin, P.; Netto, K. Validation of GPS and Accelerometer Technology in Swimming. *J. Sci. Med. Sport* **2014**, *17*, 234–238. [CrossRef] [PubMed]
50. Kos, A.; Umek, A. Wearable Sensor Devices for Prevention and Rehabilitation in Healthcare: Swimming Exercise with Real-Time Therapist Feedback. *IEEE Internet Things J.* **2019**, *6*, 1331–1341. [CrossRef]
51. Benson, L.C.; Clermont, C.A.; Bošnjak, E.; Ferber, R. The Use of Wearable Devices for Walking and Running Gait Analysis Outside of the Lab: A Systematic Review. *Gait Posture* **2018**, *63*, 124–138. [CrossRef] [PubMed]
52. Ahamed, N.U.; Kobsar, D.; Benson, L.; Clermont, C.; Kohrs, R.; Osis, S.T.; Ferber, R. Using Wearable Sensors to Classify Subject-Specific Running Biomechanical Gait Patterns Based on Changes in Environmental Weather Conditions. *PLoS ONE* **2018**, *13*, e0203839. [CrossRef]
53. Hwang, T.-H.; Reh, J.; Effenberg, A.O.; Blume, H. Validation of Real Time Gait Analysis Using a Single Head-Worn IMU. In *Proceedings of the Europe-Korea Conference on Science and Technology*; Springer: Singapore, 2019; pp. 87–97.
54. Ashry, S.; Ogawa, T.; Gomaa, W. CHARM-Deep: Continuous Human Activity Recognition Model Based on Deep Neural Network Using IMU Sensors of Smartwatch. *IEEE Sens. J.* **2020**, *20*, 8757–8770. [CrossRef]
55. Yeo, H.-S.; Feng, W.; Huang, M.X. WATouCH: Enabling Direct Input on Non-Touchscreen Using Smartwatch's Photoplethysmogram and IMU Sensor Fusion. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA, 25–30 April 2020; pp. 1–10.
56. Kos, M.; Kramberger, I. A Wearable Device and System for Movement and Biometric Data Acquisition for Sports Applications. *IEEE Access* **2017**, *5*, 6411–6420. [CrossRef]
57. Liu, Y.; Ghannam, R.; Heidari, H. Smart Multi-Sensor Wristband for Gesture Classification. In Proceedings of the IEEE UKCAS 2019, London, UK, 6 December 2019.
58. Liu, W.; Long, Z.; Yang, G.; Xing, L. A Self-Powered Wearable Motion Sensor for Monitoring Volleyball Skill and Building Big Sports Data. *Biosensors* **2022**, *12*, 60. [CrossRef]
59. Gao, X.; Zheng, M.; Lv, H.; Zhang, Y.; Zhu, M.; Hou, Y. Ultrahigh Sensitive Flexible Sensor Based on Textured Piezoelectric Composites for Preventing Sports Injuries. *Compos. Sci. Technol.* **2022**, *229*, 109693. [CrossRef]
60. Kreil, M.; Ogris, G.; Lukowicz, P. Muscle Activity Evaluation Using Force Sensitive Resistors. In Proceedings of the 2008 5th International Summer School and Symposium on Medical Devices and Biosensors, Hong Kong, China, 1–3 June 2008; pp. 107–110.
61. Mengüç, Y.; Park, Y.-L.; Pei, H.; Vogt, D.; Aubin, P.M.; Winchell, E.; Fluke, L.; Stirling, L.; Wood, R.J.; Walsh, C.J. Wearable Soft Sensing Suit for Human Gait Measurement. *Int. J. Robot. Res.* **2014**, *33*, 1748–1764. [CrossRef]
62. Raza, T.; Tufail, M.K.; Ali, A.; Boakye, A.; Qi, X.; Ma, Y.; Ali, A.; Qu, L.; Tian, M. Wearable and Flexible Multifunctional Sensor Based on Laser-Induced Graphene for the Sports Monitoring System. *ACS Appl. Mater. Interfaces* **2022**, *14*, 54170–54181. [CrossRef] [PubMed]
63. Balkhi, P.; Moallem, M. A Multipurpose Wearable Sensor-Based System for Weight Training. *Automation* **2022**, *3*, 132–152. [CrossRef]
64. Li, Q.; Dai, K.; Zhang, W.; Wang, X.; You, Z.; Zhang, H. Triboelectric Nanogenerator-Based Wearable Electronic Devices and Systems: Toward Informatization and Intelligence. *Digit. Signal Process.* **2021**, *113*, 103038. [CrossRef]
65. Li, C.; Zhu, Y.; Sun, F.; Jia, C.; Zhao, T.; Mao, Y.; Yang, H. Research Progress on Triboelectric Nanogenerator for Sports Applications. *Energies* **2022**, *15*, 5807. [CrossRef]
66. Dassanayaka, D.G.; Alves, T.M.; Wanasekara, N.D.; Dharmasena, I.G.; Ventura, J. Recent Progresses in Wearable Triboelectric Nanogenerators. *Adv. Funct. Mater.* **2022**, *32*, 2205438. [CrossRef]
67. Park, Y.-G.; Lee, G.-Y.; Jang, J.; Yun, S.M.; Kim, E.; Park, J.-U. Liquid Metal-Based Soft Electronics for Wearable Healthcare. *Adv. Healthc. Mater.* **2021**, *10*, 2002280. [CrossRef]
68. Rico-González, M.; Los Arcos, A.; Clemente, F.M.; Rojas-Valverde, D.; Pino-Ortega, J. Accuracy and Reliability of Local Positioning Systems for Measuring Sport Movement Patterns in Stadium-Scale: A Systematic Review. *Appl. Sci.* **2020**, *10*, 5994. [CrossRef]
69. Waqar, A.; Ahmad, I.; Habibi, D.; Phung, Q.V. Analysis of GPS and UWB Positioning System for Athlete Tracking. *Meas. Sens.* **2021**, *14*, 100036. [CrossRef]

70. Liu, J.; Huang, G.; Hyyppä, J.; Li, J.; Gong, X.; Jiang, X. A Survey on Location and Motion Tracking Technologies, Methodologies and Applications in Precision Sports. *Expert Syst. Appl.* **2023**, *229*, 120492. [CrossRef]
71. Szot, T.; Specht, C.; Dabrowski, P.S.; Specht, M. Comparative Analysis of Positioning Accuracy of Garmin Forerunner Wearable GNSS Receivers in Dynamic Testing. *Measurement* **2021**, *183*, 109846. [CrossRef]
72. Liu, Y. Research and Development of GNSS Wearable Device for Sports Performance Monitoring by Example of Soccer Player Analysis∗. In Proceedings of the 2022 6th International Conference on Electronic Information Technology and Computer Engineering, Xiamen, China, 21–23 October 2022; pp. 901–906.
73. Pino-Ortega, J.; Rico-González, M. Review of Ultra-Wide Band in Team Sports. In *Innovations in Ultra-Wideband Technologies*; InechOpen: Londn, UK, 2020; pp. 93–102. [CrossRef]
74. Zhang, H.; Zhang, Z.; Gao, N.; Xiao, Y.; Meng, Z.; Li, Z. Cost-Effective Wearable Indoor Localization and Motion Analysis via the Integration of UWB and IMU. *Sensors* **2020**, *20*, 344. [CrossRef]
75. Vleugels, R.; Van Herbruggen, B.; Fontaine, J.; De Poorter, E. Ultra-Wideband Indoor Positioning and IMU-Based Activity Recognition for Ice Hockey Analytics. *Sensors* **2021**, *21*, 4650. [CrossRef] [PubMed]
76. Li, X.; Shen, Y.; Qu, Y.; Wu, X.; Liu, Y. Real-Time Ski Jumping Trajectory Reconstruction and Motion Analysis Using the Integration of UWB and IMU. In Proceedings of the Methods and Applications for Modeling and Simulation of Complex Systems: 21st Asia Simulation Conference, AsiaSim 2022, Changsha, China, 9–11 December 2022; Proceedings, Part I. Springer: Singapore, 2022; pp. 463–478.
77. Nagymáté, G.; Kiss, R.M. Application of OptiTrack Motion Capture Systems in Human Movement Analysis: A Systematic Literature Review. *Recent Innov. Mechatron.* **2018**, *5*, 1–9. [CrossRef]
78. Wang, H.; Li, L.; Chen, H.; Li, Y.; Qiu, S.; Gravina, R. Motion Recognition for Smart Sports Based on Wearable Inertial Sensors. In Proceedings of the Body Area Networks: Smart IoT and Big Data for Intelligent Health Management, Florence, Italy, 2–3 October 2019; Mucchi, L., Hämäläinen, M., Jayousi, S., Morosi, S., Eds.; Springer International Publishing: Cham, Switzerland, 2019; pp. 114–124.
79. Boddy, K.J.; Marsh, J.A.; Caravan, A.; Lindley, K.E.; Scheffey, J.O.; O'Connell, M.E. Exploring Wearable Sensors as an Alternative to Marker-Based Motion Capture in the Pitching Delivery. *PeerJ* **2019**, *7*, e6365. [CrossRef] [PubMed]
80. Li, R.T.; Kling, S.R.; Salata, M.J.; Cupp, S.A.; Sheehan, J.; Voos, J.E. Wearable Performance Devices in Sports Medicine. *Sports Health* **2016**, *8*, 74–78. [CrossRef] [PubMed]
81. Kamišalić, A.; Fister, I.; Turkanović, M.; Karakatič, S. Sensors and Functionalities of Non-Invasive Wrist-Wearable Devices: A Review. *Sensors* **2018**, *18*, 1714. [CrossRef]
82. Zhao, X.; Long, Y.; Yang, T.; Li, J.; Zhu, H. Simultaneous High Sensitivity Sensing of Temperature and Humidity with Graphene Woven Fabrics. *ACS Appl. Mater. Interfaces* **2017**, *9*, 30171–30176. [CrossRef]
83. Polanskỳ, R.; Soukup, R.; Řeboun, J.; Kalčík, J.; Moravcová, D.; Kupka, L.; Švantner, M.; Honnerová, P.; Hamáček, A. A Novel Large-Area Embroidered Temperature Sensor Based on an Innovative Hybrid Resistive Thread. *Sens. Actuators Phys.* **2017**, *265*, 111–119. [CrossRef]
84. Yang, J.-H.; Cho, H.-S.; Lee, J.H. An Analysis on the Luminance Efficiency of the Machine Embroidery Method Applied to Flexible Plastic Optical Fiber for Realization of the Textile Display. *Text. Res. J.* **2018**, *88*, 1466–1478. [CrossRef]
85. Martínez-Estrada, M.; Moradi, B.; Fernández-Garcia, R.; Gil, I. Impact of Conductive Yarns on an Embroidery Textile Moisture Sensor. *Sensors* **2019**, *19*, 1004. [CrossRef]
86. van der Valk, D. Knitted Smart Textile Sensors: Integrating Technlogy into Garments by Using Knitting. Master's Thesis, Delft University of Technology, Delft, The Netherlands, 2020.
87. Erol, A.D.; Çetiner, S. Elektronik Tekstillere Yönelik Akıllı Kumaş Sensörleri. *J. Text. Eng. Tekst. Ve Mühendis* **2017**, *24*, 305–320. [CrossRef]
88. Chen, Y.; Lloyd, D.W.; Harlock, S.C. Mechanical Characteristics of Coated Fabrics. *J. Text. Inst.* **1995**, *86*, 690–700. [CrossRef]
89. Viper Pod: Technology, Rugby, Soccer, Football, Basketball. Available online: https://sportsmatik.com/sports-corner/sports-technology/viper-pod (accessed on 12 May 2023).
90. Lumo Run Review. Available online: https://www.wareable.com/running/lumo-run-review (accessed on 12 May 2023).
91. Adesida, Y.; Papi, E.; McGregor, A.H. Exploring the Role of Wearable Technology in Sport Kinematics and Kinetics: A Systematic Review. *Sensors* **2019**, *19*, 1597. [CrossRef] [PubMed]
92. Preatoni, E.; Bergamini, E.; Fantozzi, S.; Giraud, L.I.; Orejel Bustos, A.S.; Vannozzi, G.; Camomilla, V. The Use of Wearable Sensors for Preventing, Assessing, and Informing Recovery from Sport-Related Musculoskeletal Injuries: A Systematic Scoping Review. *Sensors* **2022**, *22*, 3225. [CrossRef] [PubMed]
93. Kamarauskas, P.; Lukonaitienė, I.; Kvedaras, M.; Venckūnas, T.; Conte, D. Relationships between Weekly Changes in Salivary Hormonal Responses and Load Measures during the Pre-Season Phase in Professional Male Basketball Players. *Biol. Sport* **2023**, *40*, 353–358. [CrossRef]
94. Pedersen, A.; Randers, M.B.; Luteberget, L.S.; Møller, M. Validity of Session Rating of Perceived Exertion for Measuring Training Load in Youth Team Handball Players. *J. Strength. Cond. Res.* **2021**, *37*, 174–180. [CrossRef]
95. Pernigoni, M.; Calleja-González, J.; Lukonaitienė, I.; Tessitore, A.; Stanislovaitienė, J.; Kamarauskas, P.; Conte, D. Comparative Effectiveness of Active Recovery and Static Stretching During Post-Exercise Recovery in Elite Youth Basketball. *Res. Q. Exerc. Sport* **2023**, 1–9. [CrossRef]

96. Gamble, A.S.; Bigg, J.L.; Pignanelli, C.; Nyman, D.L.; Burr, J.F.; Spriet, L.L. Reliability and Validity of an Indoor Local Positioning System for Measuring External Load in Ice Hockey Players. *Eur. J. Sport Sci.* **2023**, *23*, 311–318. [CrossRef]
97. Nunes, N.A.; Goncalves, B.; Coutinho, D.; Nakamura, F.Y.; Travassos, B. How Playing Area Dimension and Number of Players Constrain Football Performance during Unbalanced Ball Possession Games. *Int. J. Sports Sci. Coach.* **2021**, *16*, 334–343. [CrossRef]
98. Luczak, T.; Burch, R.; Lewis, E.; Chander, H.; Ball, J. State-of-the-Art Review of Athletic Wearable Technology: What 113 Strength and Conditioning Coaches and Athletic Trainers from the USA Said about Technology in Sports. *Int. J. Sports Sci. Coach.* **2020**, *15*, 26–40. [CrossRef]
99. Wilkerson, G.B.; Gupta, A.; Allen, J.R.; Keith, C.M.; Colston, M.A. Utilization of Practice Session Average Inertial Load to Quantify College Football Injury Risk. *J. Strength. Cond. Res.* **2016**, *30*, 2369–2374. [CrossRef]
100. Seshadri, D.R.; Li, R.T.; Voos, J.E.; Rowbottom, J.R.; Alfes, C.M.; Zorman, C.A.; Drummond, C.K. Wearable Sensors for Monitoring the Internal and External Workload of the Athlete. NPJ Digit. *Med.* **2019**, *2*, 71.
101. Şahin, T. Wearable Technologies in Athletic Performance. *Turk. J. Sport Exerc.* **2021**, *23*, 40–45.
102. World Aquatics Competition Regulations. 2023. Available online: https://www.worldaquatics.com/rules/www.worldaquatics.com/rules/competition-regulations (accessed on 5 September 2023).
103. Brown, S.M.; Brison, N.T. Big Data, Big Problems: Analysis of Professional Sports Leagues' CBAs and Their Handling of Athlete Biometric Data. *J. Leg. Asp. Sport* **2020**, *30*, 63. [CrossRef]
104. The Official Site of Major League Baseball. Available online: https://www.mlb.com/search (accessed on 12 May 2023).
105. FIFA Preferred Provider f. Live Player & Ball Tracking. Available online: https://kinexon.com/blog/fifa-preferred-provider-live-player-and-ball-tracking/ (accessed on 7 May 2023).
106. Bani, R.; Yamamoto, Y. Development of an R-Shiny-Based Shooting Area Visualization Application for Use in Basketball. In Proceedings of the 2022 20th International Conference on ICT and Knowledge Engineering (ICT&KE), Bangkok, Thailand, 23–25 November 2022; pp. 1–6.
107. Chardonnens, J.; Favre, J.; Cuendet, F.; Gremion, G.; Aminian, K. A System to Measure the Kinematics during the Entire Ski Jump Sequence Using Inertial Sensors. *J. Biomech.* **2013**, *46*, 56–62. [CrossRef]
108. Krüger, A.; Edelmann-Nusser, J. Biomechanical Analysis in Freestyle Snowboarding: Application of a Full-Body Inertial Measurement System and a Bilateral Insole Measurement System. *Sports Technol.* **2009**, *2*, 17–23. [CrossRef]
109. Manchado, C.; Tortosa Martínez, J.; Pueo, B.; Cortell Tormo, J.M.; Vila, H.; Ferragut, C.; Sánchez Sánchez, F.; Busquier, S.; Amat, S.; Chirosa Ríos, L.J. High-Performance Handball Player's Time-Motion Analysis by Playing Positions. *Int. J. Environ. Res. Public. Health* **2020**, *17*, 6768. [CrossRef] [PubMed]
110. Stone, J.D.; Merrigan, J.J.; Ramadan, J.; Brown, R.S.; Cheng, G.T.; Hornsby, W.G.; Smith, H.; Galster, S.M.; Hagen, J.A. Simplifying External Load Data in NCAA Division-I Men's Basketball Competitions: A Principal Component Analysis. *Front. Sports Act. Living* **2022**, *4*, 24. [CrossRef] [PubMed]
111. Medeiros, A.; Silva, G.; Simim, M.; Neto, F.; Nakamura, F.; Palermo, L.; Ramos, A.; Afonso, J.; Mesquita, I. Activity Profile of Training and Matches Activities of Women's Beach Volleyball Players: A Case Study of a World Top-Level Team. *J. Hum. Sport Exerc.* **2023**, *18*, 679–689. [CrossRef]
112. Nunes, N.A.; Gonçalves, B.; Coutinho, D.; Travassos, B. How Numerical Unbalance Constraints Physical and Tactical Individual Demands of Ball Possession Small-Sided Soccer Games. *Front. Psychol.* **2020**, *11*, 1464. [CrossRef]
113. Pi\lka, T.; Grzelak, B.; Sadurska, A.; Górecki, T.; Dyczkowski, K. Predicting Injuries in Football Based on Data Collected from GPS-Based Wearable Sensors. *Sensors* **2023**, *23*, 1227. [CrossRef] [PubMed]
114. Principe, V.A.; Seixas-da-Silva, A.; de Souza Vale, R.; Nunes, R.D.A.M. GPS Technology to Control of External Demands of Elite Brazilian Female Football Players during Competitions. *Retos Nuevas Tend. En Educ. Física Deporte Recreación* **2021**, 18–26.
115. Johnston, R.D.; Hewitt, A.; Duthie, G. Validity of Real-Time Ultra-Wideband Global Navigation Satellite System Data Generated by a Wearable Microtechnology Unit. *J. Strength Cond. Res.* **2020**, *34*, 2071–2075. [CrossRef] [PubMed]
116. Cullen, B.D.; McCarren, A.L.; Malone, S. Ecological Validity of Self-Reported Wellness Measures to Assess Pre-Training and Pre-Competition Preparedness within Elite Gaelic Football. *Sport Sci. Health* **2021**, *17*, 163–172. [CrossRef]
117. Di Paolo, S.; Nijmeijer, E.M.; Bragonzoni, L.; Gokeler, A.; Benjaminse, A. Definition of High-Risk Motion Patterns for Female ACL Injury Based on Football-Specific Field Data: A Wearable Sensors Plus Data Mining Approach. *Sensors* **2023**, *23*, 2176. [CrossRef] [PubMed]
118. Belcic, I.; Ocic, M.; Dukaric, V.; Knjaz, D.; Zoretic, D. Effects of One-Step and Three-Step Run-Up on Kinematic Parameters and the Efficiency of Jump Shot in Handball. *Appl. Sci.* **2023**, *13*, 3811. [CrossRef]
119. Vadász, K.; Varga, M.; Sebesi, B.; Hortobágyi, T.; Murlasits, Z.; Atlasz, T.; Fésüs, Á.; Váczi, M. Frontal Plane Neurokinematic Mechanisms Stabilizing the Knee and the Pelvis during Unilateral Countermovement Jump in Young Trained Males. *Int. J. Environ. Res. Public. Health* **2023**, *20*, 220. [CrossRef]
120. Camp, C.L.; Loushin, S.; Nezlek, S.; Fiegen, A.P.; Christoffer, D.; Kaufman, K. Are Wearable Sensors Valid and Reliable for Studying the Baseball Pitching Motion? An Independent Comparison With Marker-Based Motion Capture. *Am. J. Sports Med.* **2021**, *49*, 3094–3101. [CrossRef]
121. Frontani, F.; Prenassi, M.; Paolini, V.; Luciani, P.; Marceglia, S.; Policastro, F. Knee Kinematic during the Golf Swing: A Cross-Sectional Analysis between Groups of Different Handicap. *J. Phys. Educ. Sport* **2022**, *22*, 250–255.

122. Pedro, B.; Cabral, S.; Veloso, A.P. Concurrent Validity of an Inertial Measurement System in Tennis Forehand Drive. *J. Biomech.* **2021**, *121*, 110410. [CrossRef]
123. Saito, A.; Okada, K.; Sato, H.; Shibata, K.; Kamada, T.; Namiki, Y.; Terui, Y. Increased Medial Elbow Torque Is Associated with Ball Velocity Rather than a History of Medial Elbow Injuries in Youth Baseball Pitchers. *Arthrosc. J. Arthrosc. Relat. Surg.* **2023**, *39*, 719–727. [CrossRef] [PubMed]
124. Bigg, J.L.; Gamble, A.S.; Spriet, L.L. Internal Physiological Load Measured Using Training Impulse in Varsity Men's and Women's Ice Hockey Players between Game Periods. *J. Strength Cond. Res.* **2021**, *35*, 2824–2832. [CrossRef]
125. Bailey, D.; Saw, A.E.; Crowther, R.H.; Sims, K. Run Faster, Bowl Faster: In-Match Analysis of Elite Female Cricket Pace Bowlers. *J. Sport Exerc. Sci.* **2023**, *7*, 21–26.
126. Büchel, D.; Baumeister, J. A Comparison of the Most Intense Periods (MIPs) during Competitive Matches and Training over an 8-Week Period in a Male Elite Field Hockey Team. *Res. Sq.* 2023; *preprint*.
127. Lückemann, P.; Haid, D.M.; Brömel, P.; Schwanitz, S.; Maiwald, C. Validation of an Inertial Sensor System for Swing Analysis in Golf. *Proceedings* **2018**, *2*, 246.
128. Maier, D. Effect of Club Selection and Clubhead Speed on the Knee Joint during the Golf Swing. Master's Thesis, University of Waterloo, Waterloo, ON, Canada, 2018.
129. Wu, W.-L.; Liang, J.-M.; Chen, C.-F.; Tsai, K.-L.; Chen, N.-S.; Lin, K.-C.; Huang, I.-J. Creating a Scoring System with an Armband Wearable Device for Table Tennis Forehand Loop Training: Combined Use of the Principal Component Analysis and Artificial Neural Network. *Sensors* **2021**, *21*, 3870. [CrossRef] [PubMed]
130. Breen, M.; Reed, T.; Breen, H.M.; Osborne, C.T.; Breen, M.S. Integrating Wearable Sensors and Video to Determine Microlocation-Specific Physiologic and Motion Biometrics-Method Development for Competitive Climbing. *Sensors* **2022**, *22*, 6271. [CrossRef] [PubMed]
131. Costa, J.; Silva, C.; Santos, M.; Fernandes, T.; Faria, S. Framework for Intelligent Swimming Analytics with Wearable Sensors for Stroke Classification. *Sensors* **2021**, *21*, 5162. [CrossRef]
132. Wang, Z.; Shi, X.; Wang, J.; Gao, F.; Li, J.; Guo, M.; Zhao, H.; Qiu, S. Swimming Motion Analysis and Posture Recognition Based on Wearable Inertial Sensors. In Proceedings of the 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC), Bari, Italy, 6–9 October 2019; pp. 3371–3376.
133. Wang, Z.; Wang, J.; Zhao, H.; Qiu, S.; Li, J.; Gao, F.; Shi, X. Using Wearable Sensors to Capture Posture of the Human Lumbar Spine in Competitive Swimming. *IEEE Trans. Hum.-Mach. Syst.* **2019**, *49*, 194–205. [CrossRef]
134. Hu, J.; Browne, J.D.; Baum, J.T.; Robinson, A.; Arnold, M.T.; Reid, S.P.; Neufeld, E.V.; Dolezal, B.A. Lower Limb Graduated Compression Garments Modulate Autonomic Nervous System and Improve Post-Training Recovery Measured via Heart Rate Variability. *Int. J. Exerc. Sci.* **2020**, *13*, 1794.
135. Skallerud, A.; Brumbaugh, A.; Fudalla, S.; Parker, T.; Robertson, K.; Pepin, M.-E. Comparing Lumbar Lordosis in Functional Dance Positions in Collegiate Dancers With and Without Low Back Pain. *J. Danc. Med. Sci.* **2022**, *26*, 191–201. [CrossRef]
136. Bangsbo, J.; Mohr, M.; Poulsen, A.; Perez-Gomez, J.; Krustrup, P. Training and Testing the Elite Athlete. *J. Exerc. Sci. Fit.* **2006**, *4*, 1–14.
137. Akyildiz, Z. Antrenman Yükü. *CBÜ Beden Eğitimi Ve Spor Bilim. Derg.* **2019**, *14*, 152–175. [CrossRef]
138. Gabbett, T.J.; Nassis, G.P.; Oetter, E.; Pretorius, J.; Johnston, N.; Medina, D.; Rodas, G.; Myslinski, T.; Howells, D.; Beard, A. The Athlete Monitoring Cycle: A Practical Guide to Interpreting and Applying Training Monitoring Data. *Br. J. Sports Med.* **2017**, *51*, 1451–1452. [CrossRef] [PubMed]
139. Foster, C.; Rodriguez-Marroyo, J.A.; De Koning, J.J. Monitoring Training Loads: The Past, the Present, and the Future. *Int. J. Sports Physiol. Perform.* **2017**, *12*, S2-2. [CrossRef]
140. Li, R.T.; Salata, M.J.; Rambhia, S.; Sheehan, J.; Voos, J.E. Does Overexertion Correlate with Increased Injury? The Relationship between Player Workload and Soft Tissue Injury in Professional American Football Players Using Wearable Technology. *Sports Health* **2020**, *12*, 66–73. [CrossRef]
141. Coutts, A.J.; Crowcroft, S.; Kempton, T. Developing Athlete Monitoring Systems: Theoretical Basis and Practical Applications. In *Recovery and Well-Being in Sport and Exercise*; Routledge: London, UK, 2021; pp. 17–31.
142. West, S.W.; Clubb, J.; Torres-Ronda, L.; Howells, D.; Leng, E.; Vescovi, J.D.; Carmody, S.; Posthumus, M.; Dalen-Lorentsen, T.; Windt, J. More than a Metric: How Training Load Is Used in Elite Sport for Athlete Management. *Int. J. Sports Med.* **2021**, *42*, 300–306. [CrossRef] [PubMed]
143. Halson, S.L. Monitoring Training Load to Understand Fatigue in Athletes. *Sports Med.* **2014**, *44*, 139–147. [CrossRef]
144. Holden, J.T.; Houser, K.A. Taboo Transactions: Selling Athlete Biometric Data. *Fla. State Univ. Law Rev.* **2021**, *49*, 103.
145. Arnold, J.F.; Sade, R.M. Wearable Technologies in Collegiate Sports: The Ethics of Collecting Biometric Data from Student-Athletes. *Am. J. Bioeth.* **2017**, *17*, 67–70. [CrossRef]
146. Karkazis, K.; Fishman, J.R. Tracking US Professional Athletes: The Ethics of Biometric Technologies. *Am. J. Bioeth.* **2017**, *17*, 45–60. [CrossRef]
147. Brown, S.M.; Brown, K.M. Should Your Wearables Be Shareable? The Ethics of Wearable Technology in Collegiate Athletics. *Marquette Sports Law Rev.* **2021**, *32*, 97.
148. Osborne, B. Legal and Ethical Implications of Athletes' Biometric Data Collection in Professional Sport. *Marquette Sports Law Rev.* **2017**, *28*, 37.

149. Zok, M. Inertial Sensors Are Changing the Games. In Proceedings of the 2014 International Symposium on Inertial Sensors and Systems (ISISS), Laguna Beach, CA, USA, 25–26 February 2014; pp. 1–3.
150. Waltz, E. A Wearable Turns Baseball Pitching into a Science [News]. *IEEE Spectr.* **2015**, *52*, 16–17. [CrossRef]
151. Zadeh, A.; Taylor, D.; Bertsos, M.; Tillman, T.; Nosoudi, N.; Bruce, S. Predicting Sports Injuries with Wearable Technology and Data Analysis. *Inf. Syst. Front.* **2021**, *23*, 1023–1037. [CrossRef]
152. Di Paolo, S.; Zaffagnini, S.; Pizza, N.; Grassi, A.; Bragonzoni, L. Poor Motor Coordination Elicits Altered Lower Limb Biomechanics in Young Football (Soccer) Players: Implications for Injury Prevention through Wearable Sensors. *Sensors* **2021**, *21*, 4371. [CrossRef] [PubMed]
153. Strohrmann, C.; Harms, H.; Troster, G. What Do Sensors Know about Your Running Performance? In Proceedings of the 2011 15th Annual International Symposium on Wearable Computers, San Francisco, CA, USA, 12–15 June 2011; pp. 101–104.
154. Wang, X.; Qiu, J.; Fong, D.T. The Applications of Wearable Devices in the Rehabilitation of Ankle Injuries: A Systematic Review and Meta-Analysis. *Med. Nov. Technol. Devices* **2023**, *17*, 100210. [CrossRef]
155. Jildeh MD, T.; Young BS, J.; Page BS, B.; Abbas BS, M.; Evans MD, H.; Okoroha MD, K. The Use of MotusBASEBALL For Pitch Monitoring and Injury Prevention. 2021. Available online: https://digitalcommons.wayne.edu/som_srs/82?utm_source=digitalcommons.wayne.edu%2Fsom_srs%2F82&utm_medium=PDF&utm_campaign=PDFCoverPages (accessed on 6 May 2023).
156. Mizels, J.; Erickson, B.; Chalmers, P. Current State of Data and Analytics Research in Baseball. *Curr. Rev. Musculoskelet. Med.* **2022**, *15*, 283–290. [CrossRef]
157. Pantelopoulos, A.; Bourbakis, N.G. A Survey on Wearable Sensor-Based Systems for Health Monitoring and Prognosis. *IEEE Trans. Syst. Man Cybern. Part C Appl. Rev.* **2009**, *40*, 1–12. [CrossRef]
158. Rawashdeh, S.A.; Rafeldt, D.A.; Uhl, T.L. Wearable IMU for Shoulder Injury Prevention in Overhead Sports. *Sensors* **2016**, *16*, 1847. [CrossRef]
159. Timpka, T.; Jacobsson, J.; Bickenbach, J.; Finch, C.F.; Ekberg, J.; Nordenfelt, L. What Is a Sports Injury? *Sports Med.* **2014**, *44*, 423–428. [CrossRef]
160. Turner, A.P.; Barlow, J.H.; Heathcote-Elliott, C. Long Term Health Impact of Playing Professional Football in the United Kingdom. *Br. J. Sports Med.* **2000**, *34*, 332–336. [CrossRef] [PubMed]
161. FIFA. Available online: https://fifa.com (accessed on 6 May 2023).
162. Gabbett, T.J. The Training—Injury Prevention Paradox: Should Athletes Be Training Smarter and Harder? *Br. J. Sports Med.* **2016**, *50*, 273–280. [CrossRef]
163. Camp, C.L.; Tubbs, T.G.; Fleisig, G.S.; Dines, J.S.; Dines, D.M.; Altchek, D.W.; Dowling, B. The Relationship of Throwing Arm Mechanics and Elbow Varus Torque: Within-Subject Variation for Professional Baseball Pitchers Across 82,000 Throws. *Am. J. Sports Med.* **2017**, *45*, 3030–3035. [CrossRef] [PubMed]
164. Ward, P.; Tankovich, M.; Ramsden, J.S.; Drust, B.; Bornn, L. Volume and Intensity Are Important Training Related Factors in Injury Incidence in American Football Athletes. In Proceedings of the Sloan Sports Analytics Conference 2018, Boston, MA, USA, 23–24 February 2018.
165. Kenttä, G.; Hassmén, P. Overtraining and Recovery: A Conceptual Model. *Sports Med.* **1998**, *26*, 1–16. [CrossRef] [PubMed]
166. Bartlett, J.D.; O'Connor, F.; Pitchford, N.; Torres-Ronda, L.; Robertson, S.J. Relationships between Internal and External Training Load in Team-Sport Athletes: Evidence for an Individualized Approach. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 230–234. [CrossRef]
167. Wisbey, B.; Montgomery, P.G.; Pyne, D.B.; Rattray, B. Quantifying Movement Demands of AFL Football Using GPS Tracking. *J. Sci. Med. Sport* **2010**, *13*, 531–536. [CrossRef]
168. Chambers, R.; Gabbett, T.J.; Cole, M.H.; Beard, A. The Use of Wearable Microsensors to Quantify Sport-Specific Movements. *Sports Med.* **2015**, *45*, 1065–1081. [CrossRef]
169. Cardinale, M.; Varley, M.C. Wearable Training-Monitoring Technology: Applications, Challenges, and Opportunities. *Int. J. Sports Physiol. Perform.* **2017**, *12*, S2-55-S2-62. [CrossRef] [PubMed]
170. Socolow, B.; Jolly, I. Game-Changing Wearable Devices That Collect Athlete Data Raise Data Ownership Issues. *World Sports Advocate* **2017**, *15*, 15–17.
171. Jessop, A.; Baker III, T.A. Big Data Bust: Evaluating the Risks of Tracking NCAA Athletes' Biometric Data. *Tex. Rev. Entertain. Sports Law* **2019**, *20*, 81.
172. Rush, C.; Osborne, B. Benefits and Concerns Abound, Regulations Lack in Collegiate Athlete Biometric Data Collection. J Leg. *Asp. Sport* **2022**, *32*, 62.
173. Nenko, Y.; Medynskyi, S.; Maksymchuk, B.; Lymarenko, L.; Rudenko, L.; Kharchenko, S.; Kolomiets, A.; Maksymchuk, I. Communication Training of Future Sports Coaches in the Context of Neurophysiological Patterns. *BRAIN Broad Res. Artif. Intell. Neurosci.* **2022**, *13*, 42–60. [CrossRef]
174. Bartels, V.T. 9—Physiological Comfort of Sportswear. In *Textiles in Sport*; Shishoo, R., Ed.; Woodhead Publishing Series in Textiles; Woodhead Publishing: Sawston, UK, 2005; pp. 177–203. ISBN 978-1-85573-922-2.
175. Emetere, M.E. Chapter 3—Typical Environmental Challenges. In *Numerical Methods in Environmental Data Analysis*; Emetere, M.E., Ed.; Elsevier: Amsterdam, The Netherlands, 2022; pp. 41–51. ISBN 978-0-12-818971-9.
176. Djongyang, N.; Tchinda, R.; Njomo, D. Thermal Comfort: A Review Paper. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2626–2640. [CrossRef]

177. Majumdar, A.; Mukhopadhyay, S.; Yadav, R. Thermal Properties of Knitted Fabrics Made from Cotton and Regenerated Bamboo Cellulosic Fibres. *Int. J. Therm. Sci.* **2010**, *49*, 2042–2048. [CrossRef]
178. Wang, F.; Shi, W.; Lu, Y.; Song, G.; Rossi, R.M.; Anaheim, S. Effects of Moisture Content and Clothing Fit on Clothing Apparent 'Wet'Thermal Insulation: A Thermal Manikin Study. *Text. Res. J.* **2016**, *86*, 57–63. [CrossRef]
179. Abreu, M.J.A.M.; Catarino, A.P.; Cardoso, C.; Martin, E. Effects of Sportswear Design on Thermal Comfort. In Proceedings of the AUTEX 2011 Conference, Mulhouse, France, 8–10 June 2011.
180. Fantozzi, F.; Lamberti, G. Determination of Thermal Comfort in Indoor Sport Facilities Located in Moderate Environments: An Overview. *Atmosphere* **2019**, *10*, 769. [CrossRef]
181. Bartels, V.T. Physiological Comfort of BiofunctionalTextiles. Biofunctional Text. *Skin* **2006**, *33*, 51–66.
182. Bertaux, E.; Derler, S.; Rossi, R.M.; Zeng, X.; Koehl, L.; Ventenat, V. Textile, Physiological, and Sensorial Parameters in Sock Comfort. *Text. Res. J.* **2010**, *80*, 1803–1810. [CrossRef]
183. Kayseri, G.Ö.; Özdil, N.; Mengüç, G.S. Sensorial Comfort of Textile Materials. In *Woven fabrics*; IntechOpen: London, UK, 2012; pp. 235–266. ISBN 953-51-0607-4.
184. PDD Technology in Sport: Competitive Edge or Unfair Advantage? Available online: https://www.pddinnovation.com/technology-sport-competitive-edge-unfair-advantage/ (accessed on 31 May 2023).
185. Yang, P.; Shi, Y.; Li, S.; Tao, X.; Liu, Z.; Wang, X.; Wang, Z.L.; Chen, X. Monitoring the Degree of Comfort of Shoes In-Motion Using Triboelectric Pressure Sensors with an Ultrawide Detection Range. *ACS Nano* **2022**, *16*, 4654–4665. [CrossRef]
186. Zhang, J.; Yang, Z.; Liang, X. Development and Prospects of Triboelectric Nanogenerators in Sports and Physical State Monitoring. *Front. Mater.* **2022**, *9*, 902499. [CrossRef]
187. Xu, Z.; Yao, J.; Wang, Z.; Liu, Y.; Wang, H.; Chen, B.; Wu, H. Development of a Portable Electrical Impedance Tomography System for Biomedical Applications. *IEEE Sens. J.* **2018**, *18*, 8117–8124. [CrossRef]
188. Adler, A.; Holder, D. *Electrical Impedance Tomography: Methods, History and Applications*; CRC Press: Boca Raton, FL, USA, 2021; ISBN 978-0-429-68088-5.
189. Zhu, J.; Snowden, J.C.; Verdejo, J.; Chen, E.; Zhang, P.; Ghaednia, H.; Schwab, J.H.; Mueller, S. EIT-Kit: An Electrical Impedance Tomography Toolkit for Health and Motion Sensing. In Proceedings of the 34th Annual ACM Symposium on User Interface Software and Technology, Virtual Event, 10–14 October 2021; pp. 400–413.
190. McIntosh, J.; Marzo, A.; Fraser, M. SensIR: Detecting Hand Gestures with a Wearable Bracelet Using Infrared Transmission and Reflection. In Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology, Québec City, QC, Canada, 22–25 October 2017; Association for Computing Machinery: New York, NY, USA, 2017; pp. 593–597.
191. Maereg, A.T.; Lou, Y.; Secco, E.L.; King, R. Hand Gesture Recognition Based on Near-Infrared Sensing Wristband. In Proceedings of the 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2020), Valletta, Malta, 27–29 February 2020; pp. 110–117.