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Article

Application of wearable nano biosensor in sports

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Abstract: Biosensor is a new type of detection and analysis device. Because of its sensitivity, accuracy, ease of use and the ability of online and in vivo monitoring, it can be applied to all walks of life. Biosensors have a broad market in the field of sports science, which can be used for timely monitoring of sports training, and would also become an important method and technology in sports education and sports research. First of all, through consulting a large number of literature and practical research methods, the main body of the article was studied. In the introduction, the first paragraph introduced the background and leaded to the following, then summarized the research direction of scholars on sports and wearable nano biosensors, and finally made a summary; in the second part, the model of sensor related utilization algorithm was established, and various algorithms were proposed as the theoretical basis for the research on the application of wearable nano biosensors in sports; then it described the factors of nano biosensor and application in sports; finally, combined with the method part, the comparative experimental analysis of nano biosensors in the sports prospect was carried out. The results showed that the effectiveness of the algorithm model for the development of sports was improved by 7.83%.

Keywords: sports activities; wearable nano-biosensors; new sensors; wavelet transform algorithm

1. Introduction

At present, the sports trend is rising all over the world. In addition to nanosensors, optical sensors, chemical sensors and mechanical sensors are also widely used in the field of sports. Optical sensors can provide accurate measurement of physical parameters, such as light intensity and wavelength, and are suitable for analyzing sports environments. Chemical sensors are good at detecting biochemical markers in athletes' sweat or breath, providing insights into metabolic processes during exercise. Mechanical sensors can monitor physical forces and movements, such as pressure and acceleration, and provide detailed data on athletes' biomechanics. Sports software such as smart watches, sports bracelets, and smartphones have also developed rapidly. However, its function is still very simple. It can only detect the body's movement time, distance, step length, step frequency, step number, heart rate during exercise, etc. These indicators have no great effect on the training of high-level athletes. Through the real-time monitoring of the sports process, respiratory state detection, psychological response at all stages of the sports process, sports intensity, and physiological and biochemical indicators during the sports process, the athletes' sports ability and intensity can be monitored in real time. In sports, wearable biosensors can reflect the physiological signals and sports behaviors of athletes during sports. It can be completely embedded into the athlete's smart bracelet, headband, sportswear and socks, making this physiological monitoring reach a completely natural state.

Now it is gradually decreasing. The fast-paced life has brought people a lot of comfort, but at the same time, it has also led to a large increase in obesity and even diseases, which has a lot to do with inactivity. On this basis, many scientists have studied the application of sports. Gangwar et al. thought that intelligent recognition technology has made great progress in the field of transportation, and its application in sports has attracted much attention [1]. Wang and Yin believed that the Internet provided a good teaching platform for the innovation of physical education teaching mode, thus providing many physical resources, computerization and modern teaching technology [2]. Isra et al. believed that in response to the growing development of China's sports and fitness industry, the current management of members in the sports and fitness industry is incompatible with the development of China's sports and fitness industry [3]. Wang and Zheng aimed to study the use of Internet of Things information security in sports training and education computerization, and correctly and objectively evaluate and understand the information security level of the Internet of things [4]. Ballen et al. mainly studied the application of nano system combined with optical and chemical therapy in the treatment of sports rehabilitation disorders [5]. Kim et al. used big data technology and the Internet of things technology to participate in sports training and youth sports, providing valuable reference for promoting basic training for Chinese youth [6]. Wei et al. believed that although AI research is still in its infancy, it is very important to study how AI is applied to sports training, because this new technology can increase people's physical training to a certain extent [7]. Sports have been hotly discussed in life, but also attracted attention in academia.

Wearable sensor has attracted much attention because it can continuously and real-time monitor biological physiological and biochemical signals in a dynamic, non-invasive way. Scientists have provided extensive insights into the research and application of wearable nano biosensors. Mo et al. has explored that most of the current researches mainly collect and monitor users' movement and sleep conditions through motion sensors, and do not involve real physiological data [8]. Gupta et al.'s research found that the implantable and wearable biosensors for long-term monitoring of physiological and biochemical parameters are attractive for early and pre symptom diagnosis of pathological conditions and rapid clinical intervention [9]. Ma et al. thought it is worth noting that the equipment that can be applied to film on textiles has a fixed flexible bending time and can conduct thousands of cycles [10]. Liu et al. believed that biosensors based on nanoribbons and nanowires have attracted much attention. However, most biosensors are realized by using a large number of electrodes or wire networks, so it is impossible to actually wear biosensors [11]. Chauhan et al. explored graphene, which has been studied as a reference material for various applications across many scientific and engineering disciplines. Their wide application in biosensor production has opened up new possibilities for early diagnosis of life-threatening diseases and real-time health monitoring [12]. Jing et al. believed that conductive and transparent dipeptide hydrogels are considered to have good biocompatibility, versatility and physical and chemical properties similar to human tissues, and are ideal materials for manufacturing soft electronic devices and wearable biosensors [13]. Mallick et al. found that CSN (Carbon Sulphur Nitrogen) with adjustable physical and chemical properties of specific shapes and sizes were used to produce chemical sensors and biosensors [14]. Based on the sports boom, this paper studies the correlation between wearable nano biosensor and sports.

Wearable nano biosensors can evaluate athletes' physiological, biochemical markers and physical activities during training. The sensor is fully integrated into the sportsman's clothing and can monitor the whole movement process. In this paper, wearable nano biosensors are combined with sports.

2. Sensor related utilization algorithm model

Different sensors are suitable for various sports applications. Wearable nanosensors are particularly suitable for individual sports that require accurate physiological monitoring, such as running and swimming. In team sports such as football and basketball, sensors need to be robust and able to track the movements and interactions of multiple players. Therefore, the choice of sensor should be tailored to the specific needs of the sport.

2.1. Wavelet transform algorithm

When the sensor network collects data, the outliers contain some useless information, which can be collectively referred to as noise and described by $n(t)$. The raw sensor network data can be described as:

$$f(t) = s(t) + n(t) \tag{1}$$

Wavelet transform algorithm is a data processing technology in the field of land transform [15,16]. Here, the gray mean, standard deviation and information entropy of the three random algorithms are compared with the wavelet transform algorithm as shown in **Table 1**. The original sensor network data can be decomposed to specific scales to generate (m, n) wavelet coefficients of different sizes [17]. The waveform coefficient and degradation scale of silent sensor network data are m. The noise is inversely proportional to m. Based on this feature, the sensor network noise can be reduced. Sensor network data can be compressed into a. To some extent, it can improve the quality of data from sensor networks while reducing the size of data from sensor networks. The following operations have been performed:

Table 1. Gray scale mean value, standard variance, information entropy and wavelet transform algorithm comparison of the three algorithms.

	Gray mean	Standard deviation	Information entropy
Algorithm 1	145.1	1.65	7.41
Algorithm 2	125.4	1.93	7.91
Algorithm 3	139.4	1.87	7.82
Wavelet transform algorithm	141.2	1.89	7.51

1) The original sensor network data is decomposed into m scales using wavelet transform to obtain multiple wavelet coefficients in (m, n). Among them, n represents the number of wavelet coefficients;

2) The correlation degree of $w(m, n)$ and $w(m + 1, n)$ wavelet coefficients is calculated.

$$R(m,n) = w(m+1,n) \tag{2}$$

Assumptions are:

$$P_{w(m)} = \sum_{n} w\,(m,n)^2 \tag{3}$$

$$P_{R(m)} = \sum_{n} R\,(m,n)^2 \tag{4}$$

then it is:

$$N_{R(m,n)} = R(m,n) \times \sqrt{\frac{P_w(m)}{P_{R(M)}}} \tag{5}$$

The association degree is unified to narrow its value range;

3) If the condition $|N_{R(m,n)}| \geq \lambda$ is met, it means that the value of the useful sensor network data corresponding to $w(m, n)$ is unchanged; otherwise, the corresponding noise waveform is set to 0. The mathematical formula of λ is:

$$\lambda = \frac{\sqrt{\frac{P_{w(m)}}{m-1}}}{\sigma_m} \tag{6}$$

among them, σ_m represents the mean square error of $P_{w(m)}$;

4) The inverse wavelet transform is used to reconstruct the wavelet coefficients after processing, and the storage capacity of sensor network data is reduced after denoising of sensor network data [18].

2.2. Compression aware algorithm

A sensor network without data can be considered as a data sequence *x* equals *N*. In general, sequence signals have some unusual properties. A sparse transformation matrix $\psi \in R^{N \times N}$ is introduced to convert them into simple data *f*:

$$f = \psi x \tag{7}$$

Based on the principle of compressed sensing algorithm, according to the scattering signal and measurement matrix, the sample data *y* is obtained, the length is *M*, the condition is that *M* < *N*, and the sample information is:

$$y = \varphi f \tag{8}$$

The observation data can be solved by l_o norm to obtain the solution of sparse data *f*:

$$\hat{f} = \text{argmin}\,||f||_0 \tag{9}$$

$$s \times t\varphi f = y \tag{10}$$

Combining sparse data and measurement matrix can produce:

$$y = \varphi\psi x = \tilde{\varphi} x \tag{11}$$

The exact solution of *x* can be obtained according to Equation (5):

$$\hat{x} = \text{argmin}\,||x|| \tag{12}$$

$$st\varphi x = y \tag{13}$$

2.3. Adaptability of sensors under different environmental conditions

Wearable nanosensors must operate reliably under a variety of environmental conditions encountered during sports activities: factors such as high temperature, low temperature, and humidity can affect sensor performance. Therefore, it is necessary to test sensors under multiple climate conditions to ensure their robustness and accuracy. Developing sensors with enhanced environmental adaptability will improve their effectiveness in real-world sports applications.

3. Relevant factors related to the application of wearable nano biosensors in sports

3.1. Nanobiosensor factors

The application of nanotechnology in the field of biosensors has greatly improved its sensitivity, and promoted the emergence of new biosensor technologies [19,20]. With submicron transducers, probes and nano micro systems, the performance of biosensors has been greatly improved, as shown in **Figure 1**:

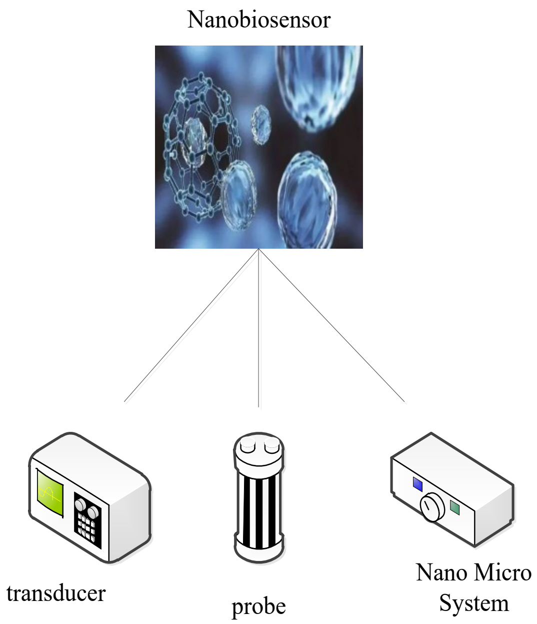

Figure 1. Nanobiosensor factors.

Nanotechnology and biotechnology are the most important technologies in the 21st century. There are many cross technologies between them, and nano biosensor is a new industry in the future. Biosensor technology is a new emerging technology that combines biology, chemistry, medicine, physics, electronics and other disciplines.

Nanotechnology is mainly aimed at the technology of the molecular world. Its scale ranges from 1 nm to 100 nm, which is located at the transition point between the micro world represented by atoms and molecules and the macro material. Systems based on this size have unique chemical and physical properties, because they are not standard microscopes or microscope systems, including surface properties composed of size, particle yield, quantum effects and macro quantum tunneling, which lack conventional advanced functions, as shown in **Figure 2**:

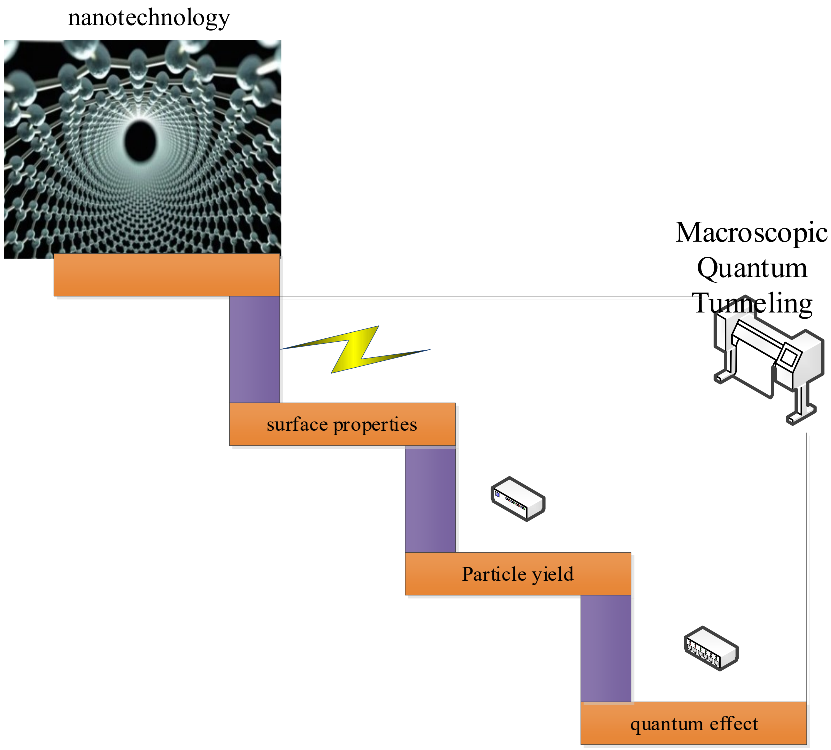

Figure 2. Surface properties of nanotechnology.

3.2. Applied factors in sports

Sports are activities carried out step by step in the process of human development, with the aim of developing physical health in cognition. The use of various sports for the former body building, such as walking, running, jumping, throwing and dancing, is usually called body exercise, as shown in **Figure 3**:

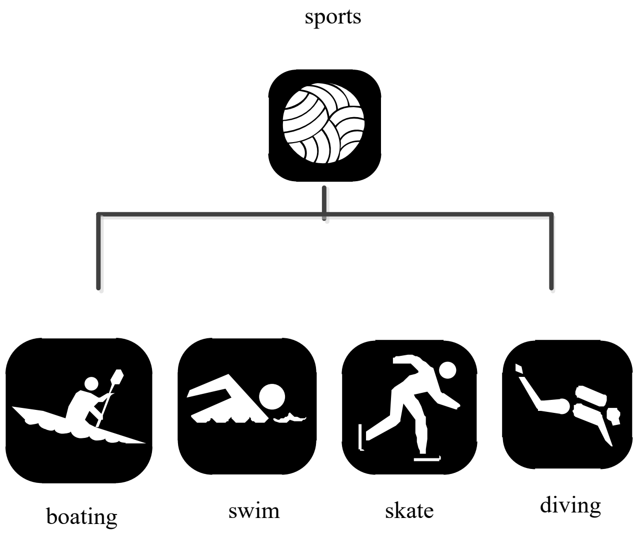

Figure 3. Application factors in sports.

Sports have the functions of fitness, entertainment, education, politics and economy. It can also be said that sports have different functions in different historical stages. However, fitness and entertainment have been its main characteristics since the beginning of sports. Sports activities are a kind of physical education activities and social cultural activities in human society.

Sports is a comprehensive social and cultural phenomenon based on sports, which can enhance physical fitness, promote health and develop various psychological qualities. Especially with the development of economy and society, people's living standards are constantly improving. People's understanding of sports is not limited to health, but also hopes to achieve psychological happiness through sports activities. For example, people watch sports, elegant dances, wonderful competitions, etc., which are pleasing to the eyes. On the competition field, people can shout loudly to vent their emotions and relax their minds as the competition goes on. A good shot and a fast-paced aerobic exercise are not only a kind of exercise, but also a kind of physical and mental relaxation, a sense of achievement, and a sense of relaxation. This is the spiritual value that sports bring to mankind.

4. Comparative experiment of nano biosensors in sports prospect

4.1. Analysis of the effect of wearable nano biosensor in respiratory monitoring

Breathing is an indicator of human function, with the increase of athletes' exercise intensity, breathing speed and heart beating speed. At present, there is a chest and abdomen breathing curve detector in the hospital, which has a good sensitivity and is suitable for wearing flat belts without direct contact with the body, and can truly reflect the breathing law. Through calibration and signal processing, respiratory rate, duration of inspiratory flow, tidal volume, flow rate and other parameters can be obtained. This new type of biosensor can be worn on nano materials. When it is applied to pressure or pressurization, it can sense the breathing speed, so as to measure the expansion and contraction of the chest. The sensor is suitable for elastic sportswear in front of the chest. When breathing, it can make the transducer with widened chest produce greater compression conductivity. During exhalation, the chest would contract, and the conductivity generated by the sensor would return to its reference value. Clothes can be made of elastic woven materials. During exercise, people can measure their breath, evaluate their physical strength and resilience, and get biochemical feedback in time. **Figure 4** shows the comparative experimental analysis of the respiratory monitoring effect between the thoracic and abdominal respiratory waveform sensor and the nano biosensor.

It can be seen from the figure that this experiment has analyzed the effects of five types of sensors in respiratory monitoring, including respiratory rate, SP02, abnormal respiratory monitoring, PETCo2, and pulmonary function monitoring. The above two kinds of sensors are introduced in detail, and their data are obtained according to their advantages and disadvantages combined with the actual situation. First, the actual effects of breath rate, SP02, abnormal breath monitoring, PETCo2, and pulmonary function monitoring in waveform sensors are 97%, 94%, 95%, 90%, and 93%; secondly, the actual effects of breath rate, SP02, abnormal breath monitoring, PETCo2 and pulmonary function monitoring in nano sensors are 95%, 96%, 94%, 93% and 97%. The following conclusions can be drawn: the respiratory rate effect of waveform sensor and abnormal respiratory system are better; SP02, PETCo2 and pulmonary function monitoring of nano sensor are superior to waveform sensor.

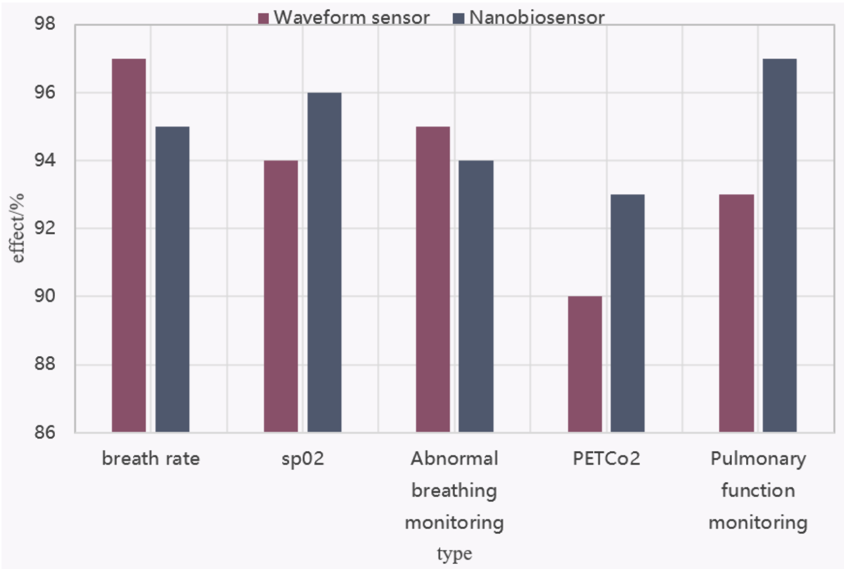

Figure 4. Comparison of the respiratory monitoring effect of the two sensors.

4.2. Wearable nano biosensor in ECG monitoring

The nano wearable biosensor applied to the monitoring of organs in the sports center can collect the sports organs near the human heart, and track the parameters such as heart rate, cardiac contraction, cardiac output, etc. In the process of sports, the ECG of athletes can be observed in real time. Once abnormalities are found, training and competition can be stopped in time to avoid accidents. The upcoming ECG can accurately detect the various indexes of the athlete's heart in sports and quantify them, so as to show the human health and possible risks to coaches through corresponding software. **Figure 5** shows the monitoring and measurement of body data by ordinary sensors and nano sensors in ECG monitoring:

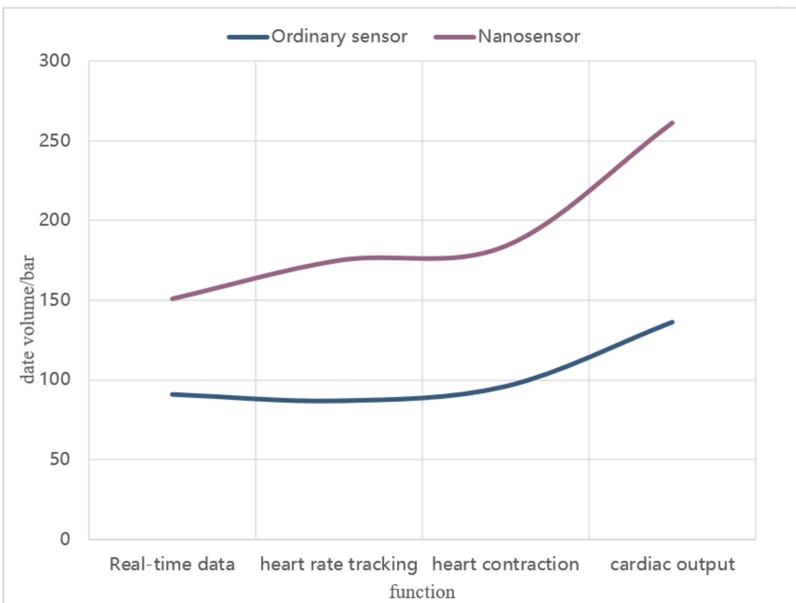

Figure 5. Two sensors monitor the amount of body data in ECG monitoring.

It can be seen from the figure that the data monitoring and analysis are carried out through the four functions of real-time data, heart rate tracking, cardiac contraction and cardiac output in ECG monitoring. The data volume of ordinary sensors in ECG monitoring function is 91, 97, 96, 136, and that of nano sensors in ECG monitoring function value is 151, 175, 184, 261. The difference between the two sensors can be more clearly drawn through data comparison: the data volume of the nano sensor in the real-time data function is about 1.65 times that of the ordinary sensor, the data volume of nano sensors in heart rate tracking function is about 1.8 times that of ordinary sensors, the data volume of nano sensors in cardiac systolic function is about 1.91 times that of ordinary sensors, and the data volume of nano sensors in cardiac output function is about 1.91 times that of ordinary sensors.

4.3. Wearable nano biosensor in EEG monitoring

By developing nano biosensors, real-time monitoring of athletes in the process of sports is realized. Its basic principle is to monitor brain waves through inductance. In this sensor, it can be controlled through Bluetooth and external software. Through real-time data feedback, athletes can fall into deep meditation without any distractions. At present, medical research achievements on meditation, introspection and other aspects emerge in endlessly. Many studies have shown that meditation can reduce blood pressure, relieve anxiety, depression and even pain, enhance personal balance, relieve stress skills, and improve sleep status. In the future, EEG can monitor human brain activity and feel people's mood and mood, which is not only a brain exercise, but also a new way of entertainment. **Figure 6** shows the comparison before and after EEG monitoring using nano biosensors:

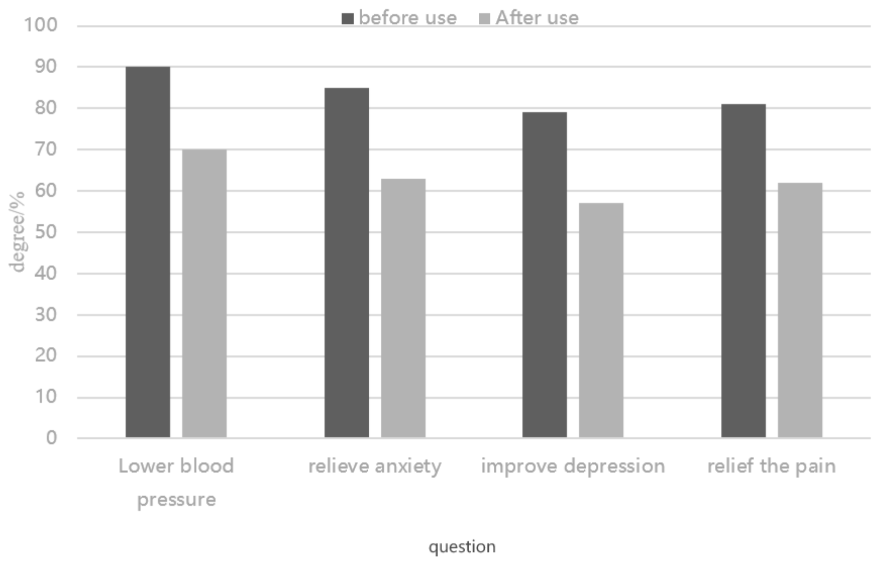

Figure 6. Comparison of nanobiosensors before and after EEG monitoring.

This part assumes the application of nano biosensors in EEG monitoring. As shown in **Figure 6**, the impact on EEG monitoring before and after the use of nano biosensors is still large. First, the data were analyzed. Before use, the degree values of lowering blood pressure, relieving anxiety, improving depression and relieving pain were 90%, 85%, 79% and 81%; the degree of lowering blood pressure, relieving anxiety, improving depression and relieving pain before use was 70%, 63%, 57% and 62%. It can be seen that the degree of problems in the above brains has been reduced to a certain extent after use. Among them, anxiety relief and depression improvement were both reduced by 22%, so it can be speculated that these two functions would be better developed in the future when nano biosensors are used in EEG monitoring.

4.4. Analysis of wearable nano biosensor in plantar sensing

Motion control is the basis of motion technology. Sports competition is not about standing still, but about posture. At present, there are many methods that can be used to test the performance of excellent athletes, and the most common method is to use physiological and biomechanical methods in the laboratory to test and analyze. In the outdoor natural environment, the most common way is to judge whether the players' technical movements are perfect by watching and playing back. In the future, smart socks with built-in nano sensors would be a fast way. The smart socks are embedded with nano biosensors, which can monitor the running posture, movement amount, steps and running distance of athletes in real time. **Figure 7** shows the transmission analysis of the foot sensor before and after using the nano biosensor:

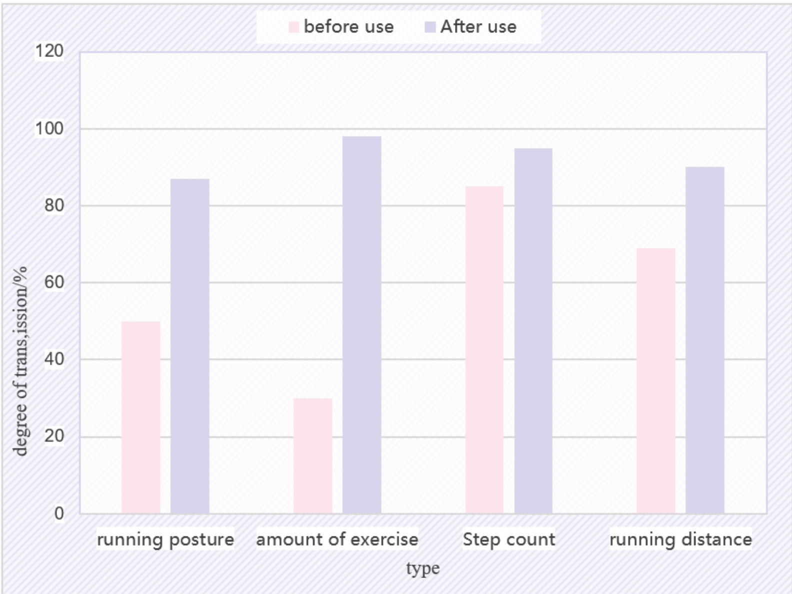

Figure 7. Transmission degree of plantar sensing using nanometer biosensors.

It can be seen from **Figure 7** that the contrast data of the front and rear transmission of nano biosensors are used in plantar sensing. The big difference is the transmission degree of the amount of motion, which is 30% and 98% before and after use, and the smallest difference is the number of steps, which is 85% and 95% before and after use. Before the use of nano biosensor, the transmission degree of running posture was 50%, and after the use, the proportion increased by about 1.74 times, to 87%; Before using the nano biosensor, the running distance transmission degree was 69%, and after using, the proportion increased by about 1.3 times, to 90%. Therefore, it can be concluded that there is still a large difference in the transmission before and after the use of nano biosensors. It is recommended to use hospital and scientific means such as biosensors in sports activities to promote the development of sports.

4.5. Satisfaction analysis of wearable nanometer biosensor in sports

Data description: after 7 days, 100 sprinters and speed skaters were selected from the gymnasium of a city to analyze the satisfaction of wearable nano biosensors in sports.

A completely natural state can be achieved without any external devices. An intelligent sensor is developed to be implanted into textiles, and all sensors on clothes are connected through wiring, so that each sensor has its own representativeness. It can not only detect the composition of sweat water, but also monitor the sports intensity in real time, so as to monitor the mental state of athletes, thus laying a foundation for scientific training. At the same time, its other potential functions would also be revealed. **Figure 8** shows the satisfaction analysis of wearable nano biosensors in sports:

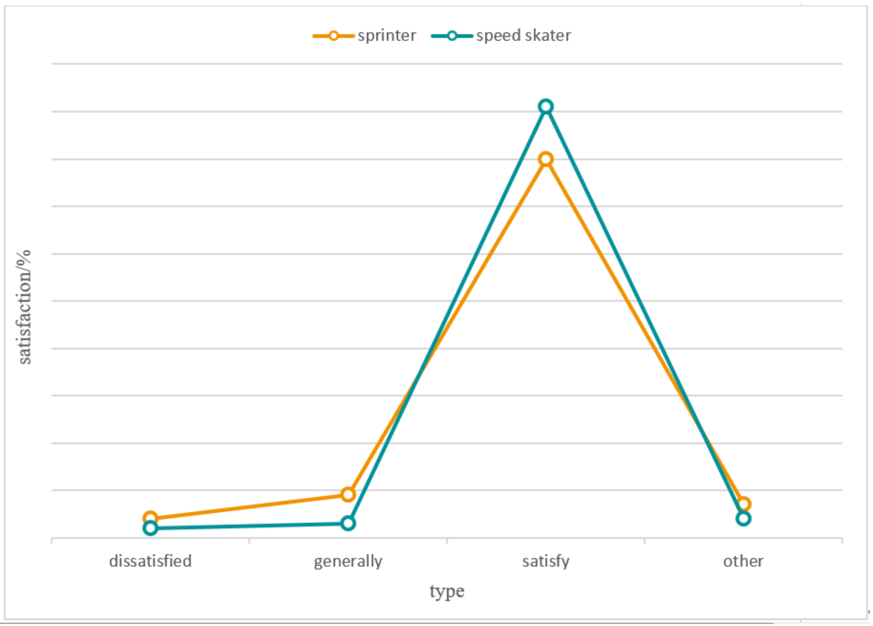

Figure 8. Analysis of the satisfaction of wearable nanobiosensors in sports.

According to **Figure 8**, the trend of the two line charts is to slowly rise, then rapidly rise, and finally rapidly fall. The survey on the satisfaction of sprinters and speed skaters shows that the number of "satisfied" athletes is far ahead, and the number is 80 and 91; the number of "dissatisfied" people is 4 or 2; the number of people who feel "average" is 9 or 3; the rest are others. It can be seen that the number of satisfied speed skaters is more than that of sprinters. It can be inferred that wearable nano biosensors may affect the accuracy of sensors when the amount of exercise is large.

To sum up, the effectiveness of the development of sports in the direction of the application of wearable nano biosensors in sports is improved by 7.83%.

4.6. Sensor performance during high-intensity exercise

To evaluate the performance of wearable nanosensors during high-intensity exercise, we designed and implemented experiments involving high-intensity exercises such as sprinting and weightlifting. During the experiments, we recorded the data accuracy, response time, and stability of the sensors at different intensity levels.

The specific experimental steps are as follows:

1) Experimental subjects: 10 healthy professional athletes aged between 20 and 30 were selected, regardless of gender.
2) Experimental design: The experimental subjects were divided into two groups, each performing two high-intensity exercises, sprinting and weightlifting. During the exercise, wearable nanosensors were used to record data such as heart rate, breathing rate, and movement trajectory.
3) Data recording: The sensor data was recorded before, during, and after the exercise to evaluate its performance in high-intensity exercise.
4) Data analysis: By comparing the data changes before and after the exercise, the sensor response time and data accuracy were analyzed.

The experimental results show that although the sensor performs well in low to moderate intensity exercise, the data accuracy and responsiveness of the sensor decrease during high-intensity exercise. In the sprint experiment, the heart rate data of the sensor fluctuated significantly within 30 s after the start of high-intensity exercise, while in the weightlifting experiment, the respiratory rate data of the sensor recovered within 1 min after the end of high-intensity exercise. This shows that the performance of existing wearable nanosensors in high-intensity exercise still needs to be optimized.

4.7. Comparison of sensor performance under different exercise intensities

To fully understand the performance of the sensor under different exercise intensities, we conducted a comparative analysis of the performance of wearable nanosensors in high-intensity and low-to-moderate-intensity exercise, including low-to-moderate-intensity exercise such as jogging and yoga and high-intensity exercise such as sprinting and weightlifting.

Experimental results show that there are significant differences in sensor performance under different exercise intensities. As shown in **Figure 9**, the sensor shows high data accuracy and stability in low-to-moderate intensity sports such as jogging and yoga, while in high-intensity sports such as sprinting and weightlifting, the sensor's data accuracy and responsiveness are poor. dropped. Specifically, the sensor's heart rate data error was less than 5% during low-to-moderate intensity exercise, while during high-intensity exercise, the heart rate data error increased to more than 10%. Additionally, during high-intensity exercise, the sensor response time is approximately 1 s longer than during low-to-moderate-intensity exercise.

These findings highlight the importance of selecting appropriate sensors based on the specific needs of the sport. In future studies, sensor technology should be further optimized to improve its performance during high-intensity exercise and to develop sensors with higher environmental adaptability.

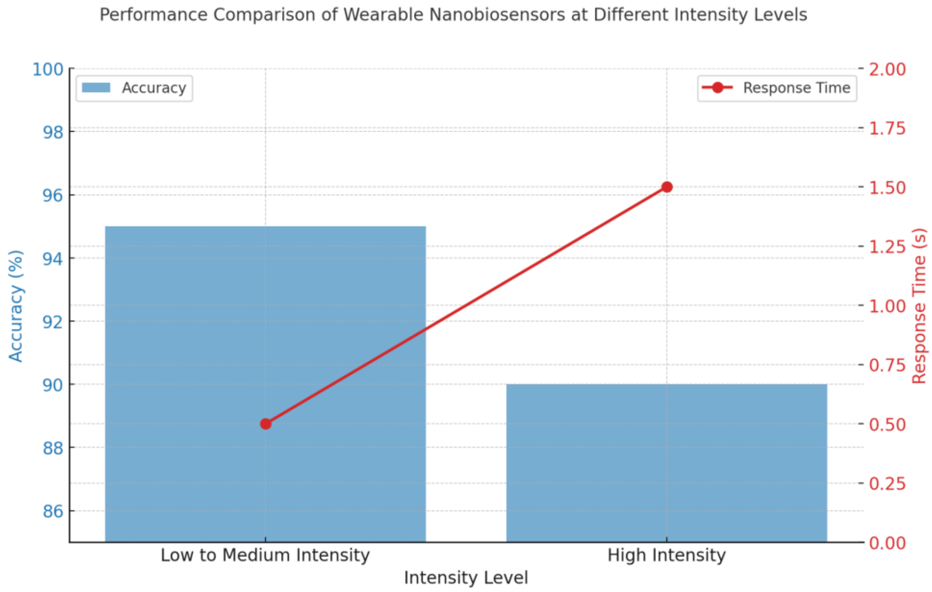

Figure 9. Comparative analysis of sensor performance under different exercise intensities.

5. Conclusions

The significance of wearable nano biosensors is to enable coaches and athletes to monitor their physical and mental conditions in sports when they can use these products, so that they can more scientifically understand the physical conditions of athletes in sports and their adaptation to sports intensity. In this paper, the experimental analysis was carried out, and the following experimental results were obtained: the satisfaction analysis of wearable nano biosensors in sports, the analysis of wearable nano biosensors in plantar sensing, the analysis of wearable nano biosensors in EEG monitoring, the analysis of wearable nano biosensors in ECG monitoring, and the analysis of wearable nano biosensors in respiratory monitoring. Finally, it was concluded that the application of wearable nano biosensors can promote the development of sports.

Author contributions: Conceptualization, LH and SH; methodology, LH; software, SH; validation, LH and SH; formal analysis, LH; investigation, SH; resources, SH; data curation, SH; writing—original draft preparation, LH; writing—review and editing, SH; visualization, SH; supervision, LH; project administration, LH; funding acquisition, SH. All authors have read and agreed to the published version of the manuscript.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

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