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Article

Protection of athletes' rights and interests: Application of biomechanics in sports law and legal issues

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Abstract: With the continuous refinement of sports law, the scientific safeguarding of athletes' rights to fair competition and their physical and mental well-being has emerged as a critical issue. This study introduces an innovative approach that integrates biomechanical technologies with a multidimensional cloud model algorithm, applied within the realm of sports law. Its primary objective is to optimize refereeing decisions and prevent sports injuries through objective data analysis. The research employs track and field events as its experimental setting, where athlete data—including joint angular displacement, angular velocity, angular acceleration, and force measurements—are captured using the Mediapipe motion capture system in conjunction with force platform technology. A multidimensional cloud model is then employed to conduct both quantitative and qualitative analyses of infractions (such as false starts) and fatigue states. Results indicate that, compared to traditional refereeing, this method not only achieves higher accuracy in identifying false starts but also effectively detects fatigue through joint motion parameters, thereby providing a robust scientific basis for athlete health monitoring. Furthermore, the study examines legal risks associated with the application of biomechanical data, such as issues related to data privacy, ownership, and evidentiary validity, and proposes compliance measures including informed consent, data encryption, and standardized protocols. Empirical findings demonstrate that biomechanical technology can significantly enhance the objectivity of adjudication, reduce misjudgment rates, and support the management of athletes' training loads—thus playing a pivotal role in maintaining fair competition and safeguarding athletes' well-being. Future research should further integrate intelligent algorithms and expand sample diversity to promote a deeper convergence between biomechanics and sports law.

Keywords: sports law; athletes' rights; biomechanical technology; cloud mode; fair play; physical and mental health

1. Introduction

As the central participants in competitive sports, athletes should be entitled to fair competition while also receiving adequate protection for their physical and mental health. However, certain infractions in sports competitions may be difficult to detect or subject to controversial rulings, thereby undermining athletes' rights to fair play. Moreover, the intense physical demands of training and competition can lead to injuries and considerable psychological stress, which in turn may negatively impact athletic performance and overall quality of life [1]. Therefore, establishing a scientific and systematic framework for athlete rights protection is of paramount importance.

In recent years, the continuous development of the sports industry has driven the refinement of sports law, which plays an increasingly significant role in safeguarding athletes' rights and regulating sports conduct. Legal frameworks not only ensure the physical and mental health of athletes but also provide clear guidelines for resolving disputes in sporting events, thereby upholding fairness and transparency in competitions [2].

With the extensive application of biomechanical technology in sports training, injury prevention, and performance evaluation, researchers can now employ data-driven approaches to quantify athletes’ conditions. Biomechanics enables an in-depth analysis of movement mechanisms and offers a scientific basis for assessing athletic performance and optimizing training programs [3]. The advancement of this technology provides novel and objective means for evaluating competition fairness and preventing sports-related injuries.

Exploring the intersection between biomechanics and sports law contributes to the establishment of a more comprehensive athlete rights protection framework. Utilizing biomechanical data to develop scientific monitoring systems for athlete health and standardized criteria for fair competition not only enhances athlete protection but also offers robust theoretical and practical support for sports law in adjudicating disputes.

This study aims to explore how biomechanical technology can provide a scientific basis for safeguarding athletes’ rights, with a particular focus on protecting their physical and mental health as well as ensuring fair competition. This study proposes an approach that integrates biomechanical technology into sports law by combining biomechanical analysis with intelligent computational algorithms to facilitate the identification of rule violations. By offering objective evidence for adjudicating infractions, this approach seeks to enhance the protection of athletes’ rights.

To systematically and comprehensively examine the application of biomechanical technology in athlete rights protection and its associated legal implications, this thesis is structured as follows: Section 1 introduces the research background, significance, objectives, and overall structure of the study. Section 2 reviews existing biomechanical technologies and their applications, discusses legal frameworks within sports law that protect athletes’ rights, and explores the application of cloud models in various domains. Section 3 presents the biomechanical technologies and methodologies employed in this study, detailing the data collection, processing, and analysis procedures while outlining the rationale for method selection and expected outcomes. Section 4 conducts a comprehensive statistical analysis of the collected biomechanical data and simulates legal case studies, comparing the proposed approach with human judgment to validate the effectiveness of biomechanical technology and intelligent computational algorithms in athlete rights protection. Section 5 discusses the legal challenges associated with applying biomechanical technology to athlete rights protection and proposes measures to mitigate legal risks. Section 6 summarizes the research findings, reflects on encountered challenges and limitations, and provides targeted recommendations for improvement and future research directions. Additionally, this section explores the theoretical and practical implications of this study in enhancing mechanisms for athlete rights protection.

This paper demonstrates the effectiveness of applying biomechanics in sports law through a systematic discussion across these sections. It offers new theoretical insights and practical solutions for protecting athlete rights. By fostering a deeper integration of biomechanical technology with sports law, this study contributes to safeguarding athletes' physical and mental health while promoting fairness in competition.

2. Related work

In recent years, various biomechanical technologies, including motion capture systems, force platforms, electromyography (EMG), inertial measurement units (IMUs), wearable sensors, high-speed video analysis, three-dimensional motion analysis systems, and computational modeling and simulation, have been widely applied in the field of sports science. Motion capture systems enable precise tracking of athletes' movement trajectories and joint angles during training and competition, providing a robust data foundation for skill assessment and injury risk prediction [4]. Utilizing motion capture technology, numerous studies have analyzed the impact of fatigue on activities such as dance and soccer, leading to the development of optimized training programs that mitigate fatigue-related effects [5,6].

Force platform technology measures ground reaction forces, offering objective insights into force distribution during key movements such as jumping and landing, which is crucial for injury prevention and rehabilitation program design [7]. Electromyography (EMG) technology monitors muscle electrical activity, allowing researchers to assess muscle load and fatigue levels, thereby facilitating the optimization of training plans and injury prevention strategies [8]. Moreover, IMUs and wearable sensors, due to their portability and real-time monitoring capabilities, have been extensively employed for long-term tracking of dynamic movement states [9]. High-speed video analysis and three-dimensional motion analysis systems, leveraging multi-angle capture and data model reconstruction techniques, enhance movement analysis precision and provide essential technical support for evaluating movement legality and ensuring fair competition in sports events [10]. Computational modeling and simulation techniques further contribute by mathematically modeling and simulating biomechanical data, effectively replicating force conditions during athletic movements, thus offering both theoretical insights and practical guidance for athlete health monitoring and injury prevention.

Scholars both domestically and internationally have conducted extensive theoretical and practical explorations on the protection of athletes' physical and mental health [11]. By utilizing physiological indicators such as heart rate, blood oxygen levels, and electromyographic (EMG) activity, in combination with psychological assessment tools, researchers have monitored and evaluated athletes' physical loads and psychological stress during high-intensity training and competition. Numerous applied case studies demonstrate that health monitoring systems based on biomechanical data can effectively prevent sports injuries and enable early intervention in psychological stress, thereby safeguarding athletes' long-term well-being [12].

In the field of sports law, the principle of fair competition serves as the cornerstone for ensuring the integrity of sporting events. The Sports Law of the People's Republic of China explicitly mandates the advancement of scientific research, development, and application in sports training, stipulating that athletes must undergo scientific and civilized training to maintain their physical and mental health [13].

These provisions aim to prevent injuries and psychological stress resulting from improper or excessive training, thereby ensuring the long-term health of athletes. Furthermore, sports law prescribes that the selection and formation of teams for major domestic and international competitions must adhere to principles of openness, fairness, and merit-based selection, ensuring a just competitive environment. It also establishes the principle of fair play in sporting events, requiring organizers, athletes, coaches, and referees to strictly abide by sports ethics and competition regulations, explicitly prohibiting fraudulent activities and corruption [13]. Through these legal provisions, sports law not only provides a legal foundation for protecting athletes' physical and mental health through scientific training but also institutionalizes mechanisms to uphold the integrity of sports competitions, thereby fostering the orderly and sustainable development of the national sports industry. Additionally, legal scholars have explored the role of legislative measures in safeguarding athletes' rights to equal participation in competitions [14].

Cloud models, which integrate probability theory and fuzzy mathematics, facilitate the transformation between qualitative concepts and quantitative data and have been applied across various fields [15,16]. The multidimensional cloud model, leveraging the principles of non-uniformity and asymmetry, enables a more accurate characterization of spatial object features, reveals latent spatial distributions, and achieves more precise spatial segmentation in complex scenarios [17]. Previous research has combined the multidimensional similarity cloud model (MSCM) with a stochastic weighting approach to evaluate lake eutrophication data [18]. Other studies have proposed multidimensional linked cloud models to describe indicator uncertainty and distribution characteristics as well as classification boundary fuzziness, which have been utilized in rockburst prediction [19]. Furthermore, multidimensional cloud models have been applied in the segmentation of fine motor movements in power grid operations, enhancing motion evaluation functions in smart grid training systems [20].

In summary, the existing literature provides substantial theoretical support and practical case studies for this study, outlining a clear research pathway for the construction of a comprehensive athlete rights protection system. The objectivity of biomechanical data offers strong judicial support, contributing to increased fairness and transparency in officiating decisions. Additionally, cloud models enable the transformation between quantitative measurements and qualitative concepts, assisting coaches in evaluating athletes' physical conditions and helping referees adjudicate disputed fouls. Biomechanical technologies hold promising applications in the field of sports law, and interdisciplinary research between biomechanics and legal studies not only ensures the protection of athletes' rights but also contributes to the continuous refinement of relevant legislation.

3. Method

3.1. Overview of the experimental procedure

This study proposes a method that combines biomechanical technology with multidimensional cloud model algorithms and applies biomechanics to sports law to better protect the rights and interests of athletes. This method can objectively evaluate the physical condition of sports and reasonably judge controversial fouls. To verify the effectiveness of this method, this study uses track and field competitions as experimental cases.

First, five healthy male amateur track and field athletes with similar athletic levels and a professional referee with relevant experience were recruited from the local sports college. All participants were in good health and had experience in training and competition. The participants were clearly aware of the experimental content, process, and risks, voluntarily participated in the experiment, and signed the informed consent form.

The participants were aged between 19 and 22 years old (average age was 20.6 years old). All participants were in good physical health, had no major diseases or injuries, had not been injured or undergone surgery in the past six months, and were able to participate in track and field training and research-related activities normally. The physical data statistics of the participants are shown in **Table 1**.

Table 1. Physical characteristics.

	Average	**Range**
Age(years)	20.6	19–22
Height(m)	1.77	1.65–1.88
Weight(kg)	73.86	67.4–85.5
Body Mass Index (BMI) (kg/m^2)	23.58	22.78–24.19

First, each participant was asked to warm up for 15 min, including stretching and jogging, which is similar to the warm-up that track and field athletes perform before a competition. The main purpose of warming up is to increase muscle temperature and nerve reaction speed to reduce the risk of injury. Then the whole experiment was divided into two stages. The first stage studied the effectiveness of the method in identifying fouls, and the second stage studied the effectiveness of the method in identifying fatigue.

In the first stage, participants were randomly selected to start the race, and the referee was not informed that there would be fouls in the game. The fouls identified by the method proposed in this study were then compared with the referee's judgment. In the second stage, all participants were asked to participate in fatigue training and compete once before and after fatigue training. This process will collect data from participants before and after fatigue and then extract fatigue features based on the method proposed in this study to identify fatigue. The fatigue protocol fully fatigued the lower limbs of each participant by simulating a real race scenario [21]. The fatigue protocol consisted of 3 sets of running 100 m each, 6 sets of sprinting 50 m each, 3 sets of running and jumping 50 m each, 2 sets of round-trip running 3 × 50 m each, 2 sets of change of direction running 30 m each, and 3 sets of jumping 5 times each. The process of the whole experiment is shown in **Figure 1**.

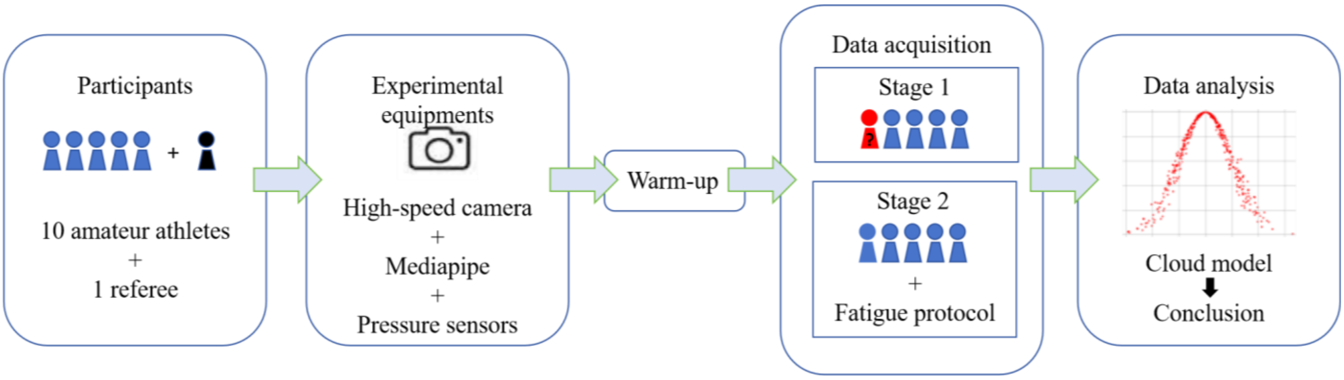


Figure 1. Outline of the experimental procedure.

3.2. Movement data capture techniques

Traditional motion capture technology primarily relies on marker-based optical systems, which employ high-frame-rate cameras and reflective markers to track an athlete's movement. These systems reconstruct three-dimensional motion trajectories with high precision using sophisticated algorithms, offering highly detailed kinematic and biomechanical parameters. However, despite their advantages in accuracy and resolution, such systems have notable limitations, including high equipment costs, strong dependence on controlled environmental conditions (e.g., specialized laboratories with strict lighting requirements), and the necessity for athletes to wear specific tracking devices, which may constrain natural movement.

In recent years, advancements in computer vision and machine learning have led to the emergence of markerless motion capture tools such as Mediapipe and Kinect [22,23]. Developed by Google, Mediapipe utilizes deep learning models for real-time human pose estimation, extracting key body landmarks from standard RGB cameras. It offers advantages such as non-intrusiveness, real-time processing, and low hardware costs. In contrast, Kinect integrates RGB imaging with depth-sensing technology, capturing depth maps to track human movement. This approach reduces system complexity, enhances adaptability to different environments, and expands the field of motion capture.

Compared to traditional motion capture methods, tools like Mediapipe and Kinect offer significant advantages in terms of experimental cost and operational convenience, substantially improving data collection efficiency and experiment reproducibility. These technologies have been widely applied in biomechanics and kinematics research related to sports science. While they may not fully match the precision of high-end optical motion capture systems, they meet the accuracy requirements for many biomechanical applications and have facilitated broader adoption in sports training, injury prevention, and rehabilitation [21,24].

Therefore, this study utilizes Mediapipe for motion capture alongside force platform technology to collect relevant biomechanical and kinematic data from participants in track and field competitions. This approach reduces experimental costs while maintaining data accuracy, thereby providing more objective and transparent data as empirical evidence. A total of five high-speed cameras were used in this study and placed on the left side of each participant to capture data related to the participants' lower extremity joints during the starting run. Pressure plates were also placed on each starting device to monitor pressure changes.

3.3. Cloud model

The cloud model algorithm is a mathematical model based on the cloud model theory, which was proposed by Chinese scientist Li Deyi in 2005. The cloud model theory is a mathematical tool for describing uncertainty, fuzziness, and randomness. It simulates the human cognitive process of uncertainty problems [25]. The cloud model algorithm is widely used in decision support, information fusion, risk assessment, and other fields [26]. The advantage of the cloud model algorithm is that it can better handle uncertainty and fuzziness and is suitable for problems that are difficult to handle with traditional mathematical methods.

The digital characteristics of the cloud include expected value E_x, entropy E_n and super entropy H_e. The expected value E_x is the expected distribution of cloud droplets in the domain space, from which the qualitative concept of the landslide state at a certain moment in the motion process can be quantitatively defined. Entropy E_n represents the degree of discreteness of cloud droplets and the range of cloud droplets in the domain space that can be accepted as belonging to each landslide state. Super entropy H_e is a measure of entropy-related uncertainty, which reflects the degree of cohesion between cloud droplets [20]. **Figure 2** is a schematic diagram of the digital characteristics of a normal cloud model.

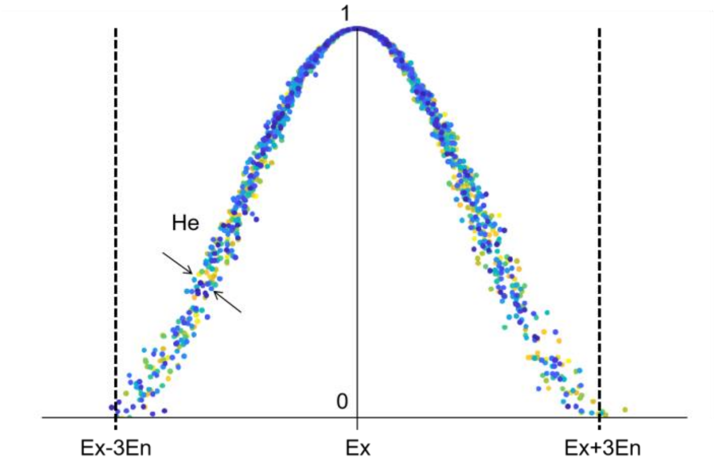


Figure 2. Schematic diagram of digital features of cloud model.

The construction process of the forward cloud generator is as follows:

(1) Determine E_x

If a variable has a specific range of variation, such as $V_{Qa}[B_{\min}, B_{\max}]$, E_x can be calculated by the following formula:

$$E_x = (B_{\min} + B_{\max})/2 \tag{1}$$

In the formula, $B_{\min}$ and $B_{\max}$ are the minimum and maximum boundaries of the variable V_{Qa}, respectively. If there is a single-bounded variable, such as $V_{Qa}[-\infty, B_{\max}]$ or $V_{Qa}[B_{\min}, +\infty]$, the missing boundary parameters or expected values can be calculated based on the upper and lower bounds, and then the digital feature E_x of the cloud can be calculated according to Equation (1).

(2) Determine E_n

Because it is necessary to comprehensively consider the changes of each variable to establish a multidimensional cloud model, the digital feature E_n of the cloud should be determined by the maximum range of each variable change, and the evaluation factor E_n remains unchanged, and E_n is determined by the following formula:

$$E_n = E_x/3 \quad (2)$$

where E_x is the different expected values corresponding to a variable. The formula here is set according to the $3E_n$ rule.

(3) Determine H_e

The digital characteristic H_e of the cloud can be selected according to the maximum range of each evaluation factor. The matching constant *k* is usually $He \leq 0.5$. If $He \geq 0.5$, the distance between cloud droplets may be too large and scattered, and the qualitative concept cannot be well expressed. The calculation formula of H_e is as follows:

$$He = kEn \quad (3)$$

(4) Forward cloud generator

The three digital features of the cloud are input, and the membership is calculated to determine the distribution of cloud droplets. In the cloud model, membership refers to the degree or probability that an object belongs to a fuzzy set. The schematic diagram of the forward cloud generator is shown in **Figure 3**.

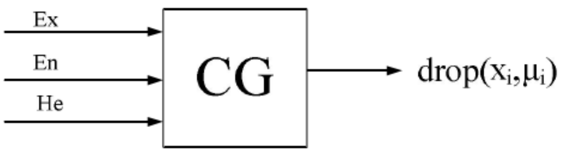


Figure 3. Forward cloud generator diagram.

The calculation formula of membership degree is as follows:

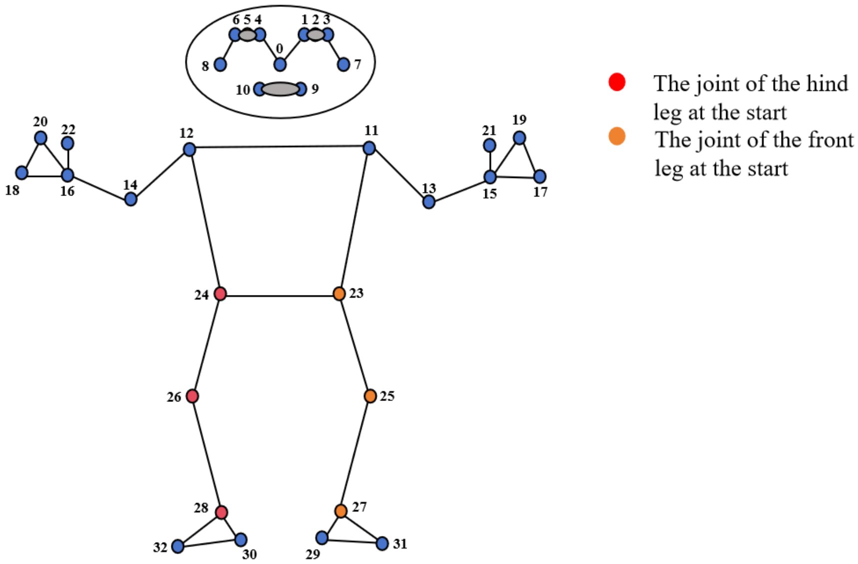
$$\mu_i = exp[-\frac{1}{d}\sum_{j=1}^{d}\frac{(x_{ji} - Ex_j)^2}{y_{ji}^2}] \quad (4)$$

where *d* represents the maximum dimension of the generated cloud model, x_{ji} is the *i*-th *j*-dimensional normal random number generated with $(Ex_1, Ex_2, ..., Ex_j)$ as the expectation and $(En_1, En_2, ..., En_j)$ as the variance, y_{ji} is the *i*-th *j*-dimensional normal random number generated with $(En_1, En_2, ..., En_j)$ as the expectation and $(He_1, He_2, ..., He_j)$ as the variance. Finally, let (x_i, μ_i) be the cloud droplet.

Through the forward cloud generator, the numerical values captured based on biomechanical technology are converted into qualitative concepts such as the athlete's physical condition or whether the athlete has committed a foul, and the hidden deep features are converted into more easily identifiable shallow features to distinguish the different actions and states of the athlete.

4. Results

By utilizing the Pose module of Mediapipe, it is possible to detect and extract 33 key body landmarks (e.g., nose, eyes, ears, shoulders, elbows, wrists, hips, knees, and ankles) in two-dimensional image coordinates while also obtaining relative three-dimensional depth information (*z*-values). This dataset serves as the foundational input for subsequent calculations, such as joint angle estimation, as illustrated in **Figure 4**. Each key point is accompanied by a confidence score, which reflects the accuracy of the detection and helps researchers assess data quality and reliability.



0.nose 1. left_eye_inner 2. left_eye 3. left_eye_outer 4. right_eye_inner 5. right_eye 6. right_eye_outer 7.left_ear 8. right_ear 9. mouth_left 10. mouth_right 11. left_shoulder 12. right_shoulder 13. left_elbow 14. right_elbow 15. left_wrist 16. right_wrist 17. left_pinky 18. right_pinky 19. left_index 20. right_index 21. left_thumb 22. right_thumb 23. left_hip 24. right_hip 25. left_knee 26. right_knee 27. left_ankle 28. right_ankle 29. left_heel 30. right_heel 31. left_foot_index 32. right_foot_index

Figure 4. Joint points of human body in Mediapipe.

This study focuses primarily on the kinematic data of the lower limb joints during the sprint start, with a particular emphasis on the right leg (the hind leg at the start). Additionally, data from the left leg (the front leg at the start) will be analyzed to provide supplementary insights.

Then, the angular displacement, angular velocity, and angular acceleration data of the hip, knee, and ankle joints can be calculated using statistical software and motion analysis software, and the pressure sensing device added to the starting block will obtain the pressure data of each participant at each start.

In the first stage, a total of 5 track and field competitions were held, and each time a participant would make a false start. The number of false starts judged by the referee and the number of false starts identified by the method proposed in this paper are shown in **Table 2**.

Table 2. False start recognition.

	Referee	The method proposed in this paper
Number of correct judgments	4	5

The results show that the accuracy of identifying false starts based on the method combining biomechanical technology with a multidimensional cloud model algorithm is higher and more objective than the human judgment of referees. Therefore, this method can provide objective and scientific reference for referees, reduce the misjudgment rate, and protect the rights of athletes to compete fairly.

Next, the specific data from the first competition will be selected for analysis, in which participant No.2 was secretly selected and needed to false start. The detailed data of the participants' hind legs at the start are shown in **Table 3**, which was recorded when the gun sounded.

Table 3. Detailed data of the first match.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Angular displacement of hip (°)	28.2	31.8	34.5	35.1	36
Angular displacement of knee (°)	38.7	42.8	38.1	43.5	41.6
Angular displacement of ankle (°)	17.8	19.5	11.6	12.9	14.3
Angular velocity of hip (°/s)	686.1	672.9	668.9	688.6	685.9
Angular velocity of knee (°/s)	−419.45	−416.95	−434.75	−420.95	−438.65
Angular velocity of ankle (°/s)	781.3	791.1	792.2	783.4	770.1
Angular acceleration of hip (°/s^2)	6527.9	6189.5	5954.9	6521.6	5972.2
Angular acceleration of knee (°/s^2)	−4576.9	−4375.4	−4498.8	−4367.7	−4328.4
Angular acceleration of ankle (°/s^2)	12,847.9	13,586.4	12,781.3	12,838.9	13,579.3
Pressure (N)	1632.5	2623.2	1532.1	1556.2	1518.6

As shown in **Table 3**, the pressure of participant No.2 who falsely starts the race, is quite different from that of other participants. Using the data in **Table 3** as the input of the forward cloud generator, we can calculate the membership degree of whether it is a foul at that moment, complete the qualitative to quantitative analysis of foul behavior, and thus identify foul behavior. The cloud model generated based on the data of each participant is shown in **Figure 5**.

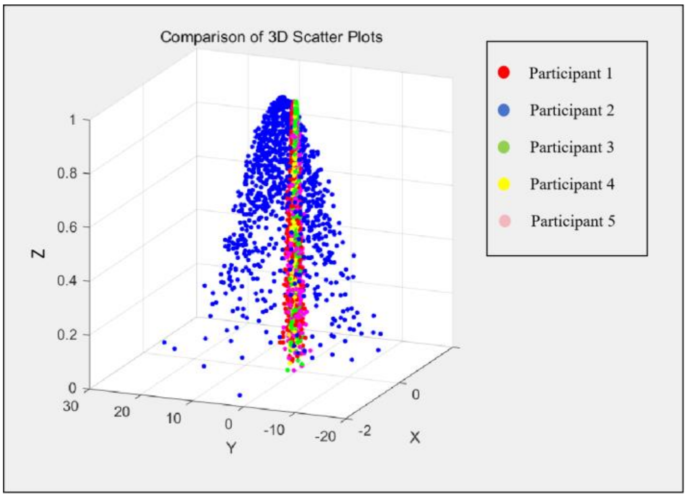


Figure 5. Multidimensional cloud model of starting foul versus normal start.

As shown in **Figure 5**, the multidimensional cloud model features generated based on the data of participants No.1, No.3, No.4, and No.5 are roughly the same, and the overlap rate of the areas where the cloud droplets are densely gathered reaches more than 90%, and there is no large offset. However, the multidimensional cloud model generated based on the data of participant No.2 has a large offset on the *Y* axis, and the range of the generated cloud droplets is wider. Therefore, the method proposed in this paper that combines biomechanical technology with the multidimensional cloud model algorithm can accurately extract the characteristics of the foul behavior of false starts, thereby providing an objective and scientific reference for the referee, reducing the misjudgment rate, and protecting the rights and interests of athletes in fair competition.

In the second stage, a total of 2 track and field competitions were held, before and after fatigue training. The detailed data of the participants' hind legs at the start are shown in **Table 4**.

Table 4. False start recognition.

	Non-fatigue mean value	**Fatigue mean value**	**Mean Difference(m/s)**
Angular displacement of hip (°)	32.3	28.7	−3.4
Angular displacement of knee (°)	40.8	42.2	+1.4
Angular displacement of ankle (°)	15.4	15.8	+0.4
Angular velocity of hip (°/s)	682.2	650.3	−31.9
Angular velocity of knee (°/s)	−428.1	−390.5	+37.6
Angular velocity of ankle (°/s)	784.1	750.1	−34.0
Angular acceleration of hip (°/s^2)	6338.3	6250.8	−88.5
Angular acceleration of knee (°/s^2)	−4553.7	−4295.3	+258.4
Angular acceleration of ankle (°/s^2)	12,751.2	11,980.5	−770.7
Pressure (N)	1572.52	1484.63	−87.89

Using the data in **Table 4** as the input of the forward cloud generator, the membership of the physical state at that moment can be calculated, and the analysis of the athlete's physical state from qualitative to quantitative can be completed so as to identify the fatigue state. The cloud model generated based on the data before and after fatigue is shown in **Figure 6**.

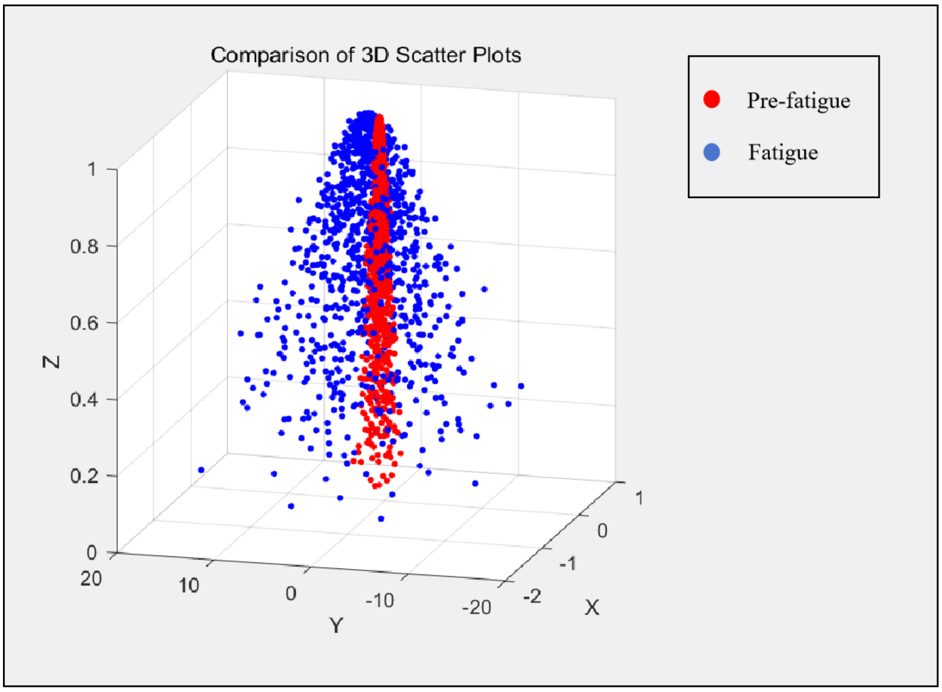


Figure 6. Multidimensional cloud model comparison of body states before and after fatigue.

As shown in **Figure 6**, the multidimensional cloud model generated based on fatigue data is quite different from that before fatigue. Therefore, the method proposed in this paper that combines biomechanical technology with the multidimensional cloud model algorithm can accurately provide the characteristics of movement under fatigue, thereby providing an objective and scientific reference for coaches to understand the physical condition of athletes, reduce the risk of injury to athletes, and protect the rights and interests of athletes' physical health.

5. Discussion

5.1. Possible legal issues in the application of biomechanical technologies

Although the relevant data obtained based on biomechanical technology can help coaches to objectively analyze the physical condition of athletes or help referees to objectively adjudicate disputed fouls, it can protect the physical and mental health of athletes and ensure fair competition. However, some legal issues may be involved when biomechanical technology is utilized to monitor the biomechanical and kinematic data of athletes.

The possible legal issues will be discussed next, and optimization suggestions will be given.

A Chinese Super League soccer club cooperated with a technology company to mandate all players to wear smart sports protective gear with built-in biomechanical sensors, which collects sensitive data such as muscle fiber activity characteristics, bone pressure distribution, and fatigue index of players in real time. The club claimed that the data was used for personalized training optimization, but without the players' individual authorization, the desensitized data was packaged and sold to a sports betting company for use in predicting the outcome of tournaments. Later, due to a security flaw in the system that led to the theft of the original data by hackers, a player's bone injury risk assessment report was leaked to social media platforms, triggering a class action lawsuit by the players.

The legal issues arising from the above case include the following four points:

(1) Data Privacy and Personal Information Protection

Biomechanical data often contain sensitive personal information related to athletes' physical characteristics and physiological indicators. Collecting, storing, or utilizing such data without obtaining explicit informed consent from the athlete may infringe upon their right to privacy and personal data protection. Existing regulations, such as the Personal Information Protection Law, impose strict requirements on the collection and processing of sensitive data. Therefore, data acquisition and handling must comply with legal and ethical standards. The collection and sharing of private data by the club in the above case without individual consent and beyond the scope of the law (Article 13, paragraph 2 of the Personal Information Protection Act) constitutes an infringement of the law.

(2) Ownership and usage rights of data

Current legal frameworks inadequately define the ownership and usage rights of biomechanical data generated during an athlete's training and competition. Allocating rights may involve multiple stakeholders, including the athlete, their affiliated club, event organizers, and technology service providers. This ambiguity can lead to disputes regarding commercial utilization, data sharing, and legal claims in litigation. China's current law does not clarify the property rights attributes of "human-derived data", so the ownership of the data in the above case is in dispute.

(3) Data security and cybersecurity risks

Biomechanical data are typically stored in electronic systems or cloud platforms. Without robust encryption and cybersecurity measures, they may be vulnerable to breaches, unauthorized modifications, or illicit use, which could lead to legal liability and compromise athletes' rights. Data security protocols must align with national regulations on cybersecurity and information protection. In the above case, if the leaked data was used for precision fraud, the player's personal rights were violated, and the player could claim moral damages under Article 1183 of the Civil Code.

(4) Lag in legal adaptation and regulatory gaps

Current laws and regulations governing the application of biomechanical technologies in sports remain underdeveloped. Some technological applications exist in a legal gray area due to the lack of explicit legislation or regulatory oversight. This lag in legal adaptation and regulatory enforcement may result in gaps in governance, creating uncertainties that could undermine athlete rights protection and fair competition. Continued legislative advancements and judicial interpretations are necessary to address these challenges. Currently, the Sports Act does not provide rules for the management of biomechanical data, which may infringe on the rights of athletes.

In summary, while biomechanics technology provides scientific support for training optimization, injury prevention, and fair competition, it simultaneously presents challenges concerning data privacy, ownership, evidentiary validity, security, and regulatory oversight. Therefore, when applying such technologies, compliance with local legal frameworks should be a priority, alongside the implementation of protective measures to mitigate legal risks and safeguard athletes' rights.

5.2. Possible measures to avoid legal problems

Based on the case study in 5.1, in order to effectively mitigate the legal risks associated with the use of biomechanical technologies in monitoring athletes' biomechanical and kinematic data, a comprehensive approach should be adopted throughout the entire data lifecycle, from collection and processing to storage and utilization. The following measures can be implemented:

(1) Establishing explicit informed consent and ownership agreements

Prior to data collection, athletes must be fully informed about the purpose, scope, methods of use, and potential risks associated with data acquisition, and their written informed consent must be obtained. Additionally, a clear agreement on data ownership and usage rights should be established to delineate the respective rights and responsibilities of athletes, affiliated institutions, clubs, and technology service providers, thereby preventing disputes related to data ownership.

(2) Enhancing data privacy and security protections

Data collection must adhere to relevant legal frameworks, such as the Personal Information Protection Law, ensuring strict protection of sensitive data (e.g., physiological indicators, motion data). Advanced security measures, including data encryption and access control, should be implemented to prevent unauthorized access or misuse. Regular security audits and risk assessments should be conducted, along with the establishment of comprehensive data backup and recovery mechanisms to ensure the security of data during storage and transmission.

(3) Standardizing data collection and processing procedures

A uniform and standardized protocol for data acquisition, calibration, and processing should be developed to ensure the accuracy, completeness, and traceability of the collected data. This is particularly critical for the legal admissibility of such data as evidence and ensures compliance with industry standards and legal requirements.

(4) Legal compliance and internal regulatory mechanisms

A dedicated database should be established, and comprehensive internal regulations governing data usage and management should be formulated. These regulations should specify data retention periods, usage scope, and conditions for data sharing, ensuring full compliance with national legal requirements. Additionally, legal counsel should be engaged for periodic evaluations of compliance, enabling timely adjustments in management strategies to adapt to evolving legal frameworks.

(5) Application of data anonymization and privacy-preserving techniques

During data analysis and research, anonymization or data masking techniques should be employed whenever possible to minimize the risk of personal identity exposure or misuse. This approach helps protect athletes' privacy when data is publicly disclosed or incorporated into research findings.

By implementing these measures, the advantages of biomechanical technologies can be fully leveraged while effectively mitigating legal disputes related to data privacy, ownership, evidentiary validity, and security risks. Ultimately, this framework enhances the protection of athletes' rights and upholds a fair and transparent competitive environment.

6. Conclusion

The research findings indicate that biomechanical data acquisition technologies can be effectively applied in sports law, enabling precise assessments of whether an athlete's physical condition is suitable for training. Compared to subjective referee judgments, biomechanical data provide a more accurate and objective basis for decision-making, thereby safeguarding athletes' rights more effectively.

The integration of biomechanical technology with multidimensional cloud models offers a more objective and transparent approach to resolving contentious officiating decisions, ensuring fair competition for athletes. This methodology allows for the accurate identification of fatigue or unhealthy states during training or competition, enabling timely rest and targeted recovery programs. Such preventive measures reduce the risk of physical injuries and contribute to the overall protection of athletes' physical and mental health. In future research, when facing ambiguous information such as controversial penalties, the cloud generator can be used to achieve the conversion of qualitative concepts to quantitative values, complete uncertainty reasoning, and extract deep features for visualization and comparison.

However, this study has certain limitations. For instance, all recruited participants were male, whereas physiological differences between male and female athletes may limit the generalizability of the findings to female football players. Additionally, the study did not account for the psychological factors influencing participants, despite the crucial role of mental health in athlete performance and health. Consider using GAN to expand the small sample dataset in future studies to reduce the cost of the experiment while increasing the generalizability of the results.

Future research will incorporate more advanced intelligent algorithms and deep learning models to enhance the application of biomechanics in sports law. For example, the Dynamic Time Warping (DTW) algorithm, a tool for assessing time-series similarity, has advantages in aligning movement data from different time sequences, enabling quantitative comparisons and anomaly detection. In sports biomechanics, DTW can compare an athlete's actual movements with an ideal motion model, identifying significant temporal deviations and providing scientific data to support officiating decisions or legal disputes. With advancements in wearable technology, real-time modeling algorithms, and interdisciplinary collaboration, these technologies are expected to achieve standardized applications across various sports, further promoting fairness and scientific rigor in competitive athletics.

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