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Article

Building a model and doing empirical research on effective exercise training in conjunction with biomechanics

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Abstract: With the rapid advancements in sports science and athletic training, the integration of biomechanics and information technology has driven the development of innovative theories and practices in sports training. Traditional training methods, which lack a scientific foundation, are increasingly seen as ineffective. In contrast, the biomechanical-based sports training model proposed in this study offers a theoretical framework for precisely enhancing athletes' performance. This model addresses several critical issues, including limited equipment adaptability, the lack of universal principles across various sports, and the challenge of tailoring training models to individual needs. To overcome these challenges, the study introduces a novel, biomechanical-based sports training model, validated through empirical research. The model is supported by a biomechanical data collection system built using multi-source sensor fusion technology, which ensures adaptability to complex training environments. This system gathers kinematic, kinetic, and electromyographic data from athletes during key activities such as double-legged downward longitudinal jumps and all-out acceleration runs. Devices like the VICON infrared camera system, a three-dimensional force measuring table, and a surface electromyography tester provide high-quality data essential for model development. Furthermore, the deep learning algorithm used in the model enhances the understanding of common principles across different sports. The model incorporates optimal designs for customized parameters to address various training needs. The empirical research employs a randomized controlled trial, dividing participants into experimental and control groups. After eight weeks of training, the model's stability and applicability across different sports are confirmed. The experimental group's training program is designed with a multi-phase approach, which includes injury prevention, targeted training, and recovery stretching, providing comprehensive support to athletes. The study's findings show that the biomechanics-based sports training model significantly improves training effectiveness and fosters the integration of theoretical and practical aspects of competitive sports and sports science. This research serves as a crucial reference point for the future development of sports training models, highlighting the importance of scientific foundations in optimizing athletic performance.

Keywords: biology; backhand twist and pull; kinematics; table tennis; movement analysis

1. Introduction

The rapid growth of modern sports science and athletic training can be attributed to the intimate integration of biomechanics and information technology. Biomechanics, an essential subject for studying the principles of human movement, provides significant support for the theoretical foundations and innovative practices of sports training [1]. Because traditional training methods are useless and imprecise in the face of the intense competition in high-level competitive sports in recent years, there is an urgent need to improve players' performance potential through scientific and methodical ways. Sports training approaches that are based on biomechanics have emerged as a crucial remedy for this issue [2,3].

Realizing the thorough enhancement of athletes' physiological processes, technical movements, and psychological capacities forms the basis of sports training. However, conventional training approaches typically rely on experience and subjective assessment, lack scientific backing and data support, and struggle to keep up with the demands of today's elite competitive sports [4]. On the other hand, biomechanics gives theoretical support for precise exercise training by quantitatively analyzing the mechanical properties and structural optimization during exercise. For instance, biomechanical analysis can provide the intricacies of the optimal movement path, which helps athletes use less energy and lower their risk of sports injuries [5,6].

The focus of international sports research has shifted to how to achieve the breakthrough of athletes' technical ability and physical condition in a short amount of time, particularly in high-intensity confrontational sports [7]. The development of an effective sports training model is crucial for advancing sports science and raising competitive levels because it not only allows for the quantitative evaluation of training effects but also serves as a guide for customized training plans for various sports [8].

The innovation and research contribution of this study lie in proposing a biomechanics-based sports training model that integrates advanced sensor fusion technology and deep learning algorithms to address existing gaps in the field. Unlike traditional approaches that focus on single-sport applications, this model combines the common laws of multiple sports with individualized parameter optimization, enabling greater adaptability across diverse training environments and athlete profiles. By dynamically analyzing multidimensional biomechanical data, the study provides a more comprehensive and practical framework for enhancing athletic performance while reducing injury risk. This integration represents a significant advancement in sports training methodologies, offering both theoretical and practical contributions to the field.

Research on biomechanics-based sports training has advanced significantly in recent years, both domestically and internationally. For instance, it is possible to dynamically analyze how athletes' biomechanical parameters change under varying training intensities by combining biomechanical simulation technology with a high-precision motion capture system; the use of artificial intelligence technology further enhances the effectiveness of data processing and decision-making [9,10]. Even while the accuracy of motion capture and mechanics measuring equipment is improving, there are still a number of significant issues with the current research, including the necessity to maximize their mobility and adaptability in complex contexts. In the meantime, it is challenging to completely address the unique biomechanical requirements for various sports. It is challenging to satisfy a variety of objectives because the majority of the training models in use today are focused on a single sport and do not refine and promote the common laws of many sports. Because athletes differ greatly in their physiological makeup, technical traits, and capacity for adaptation, the challenge of creating training regimens that are truly customized remains pressing. There aren't many large-scale, long-term empirical research to evaluate the stability and applicability of the model; most studies only go as far as theoretical formulation and brief tests [11,12].

In order to address the aforementioned issues, this study suggests and tests an effective biomechanics-based sports training model that aims to achieve innovations in both theoretical depth and practical scope [13]. This research uses multi-source sensor fusion technology to build a biomechanical data collecting system tailored to the complicated training environment. Real-time capturing of the athletes' multidimensional parameters during training allows the system to facilitate model generation with high-quality data. The training model suggested in this paper considers the applicability of various sports and individual characteristics. It uses deep learning algorithms to improve the common laws of various sports and combines them with customized parameter optimization to accommodate a range of training requirements.

The rationality of the sample size selection in this study is carefully considered to ensure scientific rigor and inclusiveness. The sample includes athletes of different genders, ages, and competitive levels, reflecting a diverse range of physiological and technical characteristics. This diversity enables the model to capture variations across these dimensions, ensuring its broader applicability and relevance. Stratified sampling techniques are employed to achieve balanced representation, enhancing the reliability and validity of the experimental findings. This approach also helps address potential biases and ensures the results are generalizable across multiple athlete demographics.

Following model construction, a comprehensive empirical investigation is carried out to confirm the model's scientific validity and application, encompassing various sports, training stages, and athlete groups.

This paper's research advances the deep integration of sports science and competitive sports in practice while also theoretically enhancing the biomechanics-based sports training model development technique. The effective sports training model developed in this work is anticipated to play a significant role in the development of future training modes by fusing cutting-edge biomechanical technology with clever training techniques. In the meantime, this paper's research findings serve as a valuable resource for scientific investigations in linked domains.

2. Research methodology

2.1. Test method

1) Biomechanical Testing

Testing Equipment and Software:

- Motion Capture System: VICON infrared camera system equipped with 8 MX13 cameras, sampling frequency of 100 Hz, running Vicon Nexus 2.6.1 software.
- Force Platform: KISTLER three-dimensional force plate (model 9287B) with a surface area of 600 mm × 900 mm and a sampling frequency of 1000 Hz.
- Marker Specifications: Markers used had a diameter of 14 mm.

To meet the modeling requirements of Visual 3D software, 41 markers were placed on specific anatomical landmarks of the subjects' bodies, and static calibration movements were recorded (**Figure 1**). The primary testing motion was the Drop Vertical Jump (DVJ), which involved the participants performing a controlled jump from an elevated position.

Participants underwent a standardized warm-up lasting approximately 10 min to reduce injury risk and prepare for the test.

Three successful trials of the DVJ were recorded for each participant. A successful trial was defined as one where the motion was completed within the biomechanical constraints and captured accurately by the motion capture system [14].

The collected data included kinematic, kinetic, and electromyographic parameters to analyze movement mechanics. The testing protocol was aligned with methodologies established in previous research. The force platform and motion capture data were synchronized to ensure precise analysis of ground reaction forces and body dynamics during the DVJ task.

The primary outcomes included vertical ground reaction forces, joint angles, and muscle activation patterns, which were used to assess performance and identify potential injury risks.

Table 1 presents the basic information of the participants in the study, providing key demographic and physical characteristics necessary to contextualize the research findings. The table includes five participants, both male and female, with the following details:

- Gender: The group consists of three males and two females, ensuring representation across genders.
- Age: The average age of the participants is 21.6 years, indicating the group primarily consists of young adults, which is typical for athletic studies focused on performance optimization.
- Height and Weight: The average height is 173.6 cm, and the average weight is 65.6 kg. These metrics reflect the general physique of active individuals and ensure comparability when analyzing biomechanical data.
- Sports Experience: Participants have an average of 4 years of sports experience, with a range from 2 to 6 years. This diversity in experience helps evaluate the biomechanics-based training model's applicability to athletes with varying skill levels and training backgrounds.

Table 1. Basic information of participants.

ID	Gender	Age (years)	Height (cm)	Weight (kg)	Sports Experience (years)
1	Male	22	178	70	5
2	Female	20	165	55	3
3	Male	23	180	75	4
4	Female	21	170	60	2
5	Male	22	175	68	6
Average	-	21.6	173.6	65.6	4.0

This data highlights the heterogeneity in participant characteristics, which supports the study's goal of developing a versatile and broadly applicable sports training model. By including athletes of different genders, body types, and experience levels, the research ensures a comprehensive evaluation of biomechanical parameters and their implications for performance and injury prevention.

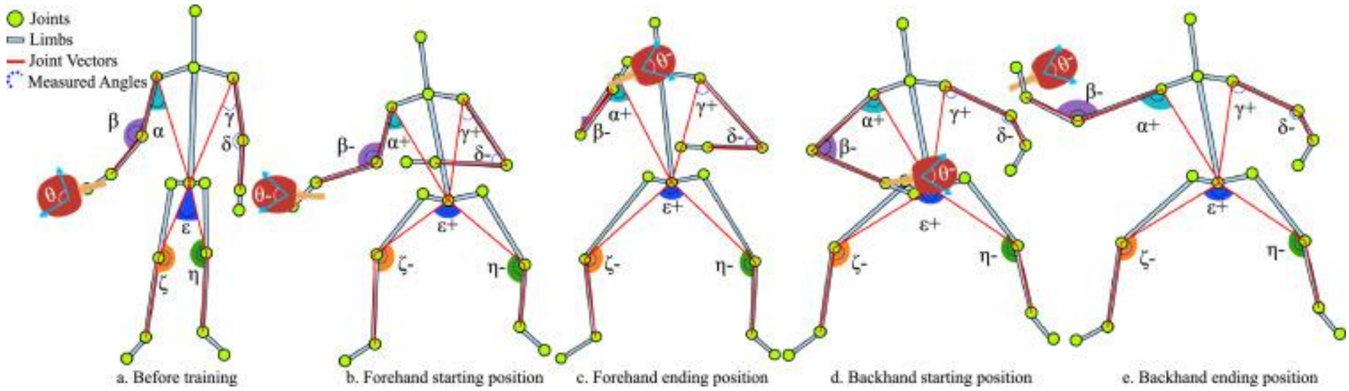

Figure 1. Location of the marker point and test site.

2) Electromyography (EMG) Testing

The electromyography (EMG) testing was conducted using a Finnish Mega ME6000 16-channel surface EMG system, targeting the following muscles: rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semitendinosus, medial gastrocnemius, lateral gastrocnemius, and tibialis anterior [15].

(1) Pre-test preparation

- Dominant Leg Identification: Each participant's dominant lower limb was identified using a standardized protocol.
- Maximum Isometric Strength Test: A maximum isometric strength test was performed for the selected muscles to normalize EMG data.
- Sensor Placement: Surface EMG sensors were positioned according to established guidelines, ensuring accurate placement over the muscle belly.
- Skin Preparation: The skin was shaved, cleaned with alcohol, and slightly abraded to minimize impedance and optimize sensor adherence.
- Calibration: The EMG system underwent calibration prior to the test to ensure data accuracy.

(2) Test protocol

Participants performed a 40-m maximum acceleration sprint using a standing start. The sprint began in response to an auditory signal. Each participant completed two trials, with a 5-min recovery interval between sprints to avoid fatigue.

(3) Data acquisition and processing

- Sampling Frequency: The EMG data was collected at a high sampling rate of 1000 Hz to capture detailed muscle activity.
- Normalization: Raw EMG signals were normalized against the maximum voluntary isometric contraction (MVIC) to facilitate comparison across participants.
- Artifact Removal: Signal artifacts caused by motion or external interference were filtered during data processing.
- Muscle Activation Analysis: The activation patterns, peak activity, and timing of each muscle were analyzed to assess performance and muscle coordination during the sprint.

(4) Enhanced protocol additions

- Video Synchronization: A high-speed camera was used to synchronize sprint movements with EMG signals for comprehensive biomechanical analysis.

- Environmental Control: The testing was conducted on a flat, non-slip surface under consistent indoor conditions to ensure performance accuracy.
- Quality Assurance: Data reliability was verified by repeating the trials if inconsistencies or anomalies were observed in the initial runs.

This enhanced testing protocol provides precise insights into the muscle activation patterns during high-intensity acceleration, supporting research into performance optimization and injury prevention.

3) Data Processing

The collected data was subjected to a systematic and precise processing workflow to ensure accuracy and reliability in analysis.

(1) Biomechanical Data Processing

- Marker Tracking: VICON Nexus software was used to track the 41 markers placed on the participants. Any gaps or errors in marker trajectory were manually corrected.
- Model Construction: The Visual 3D software constructed a biomechanical model based on the marker placement. Key joint angles, velocities, and accelerations were calculated during the drop vertical jump (DVJ).
- Force Data Synchronization: The force plate data (sampled at 1000 Hz) was synchronized with motion capture data (sampled at 100 Hz) to correlate ground reaction forces with kinematic parameters.
- Filtering: A fourth-order Butterworth low-pass filter (6 Hz cutoff for kinematic data and 15 Hz for force data) was applied to remove noise.
- Variable Extraction: Key variables such as joint angles, moments, power, and force-time characteristics were extracted for further analysis.

(2) EMG Data Processing

- Preprocessing: Raw EMG signals were band-pass filtered (20–450 Hz) and full-wave rectified to eliminate noise and improve signal quality.
- Normalization: EMG data was normalized to each participant's maximum voluntary isometric contraction (MVIC) to ensure inter-individual comparability.
- Windowing: Data was segmented into specific phases of the sprint or jump cycle (e.g., initial contact, propulsion, and landing) for phase-specific muscle activity analysis.
- Root Mean Square (RMS) Calculation: RMS values were computed over 50 ms windows to quantify muscle activation intensity.
- Co-contraction Analysis: Ratios between agonist and antagonist muscles (e.g., quadriceps and hamstrings) were analyzed to assess muscle coordination.

(3) Statistical Analysis

- Descriptive Statistics: Means and standard deviations were calculated for all variables.
- Comparative Analysis: Paired t-tests or repeated measures ANOVA were employed to compare performance between dominant and non-dominant limbs or across trials.
- Correlation Analysis: Pearson correlation coefficients were computed to explore relationships between EMG activity and biomechanical variables such as joint angles or forces.

- Significance Level: Statistical significance was set at $p < 0.05$, with Bonferroni corrections applied for multiple comparisons.
- Software Tools: MATLAB (MathWorks) and SPSS (IBM) were used for signal processing and statistical analysis, respectively.

  (4) Advanced Processing Techniques
- Wavelet Transformation: Applied to EMG signals for time-frequency analysis, providing insights into muscle activation dynamics across different movement phases.
- Cluster Analysis: Used to identify patterns in biomechanical and EMG data, grouping participants based on similar activation or kinematic profiles.

This comprehensive data processing framework ensures high data fidelity and facilitates a robust evaluation of biomechanical and neuromuscular performance metrics (see **Figure 2**). By integrating data from multiple sources, including kinematic, kinetic, and electromyographic signals, the framework offers a holistic understanding of athletes' movement dynamics. The use of advanced data filtering techniques, real-time processing, and synchronization between sensors guarantees the accuracy and reliability of the collected data. Furthermore, the framework supports the identification of key performance indicators, such as joint angles, muscle activation patterns, and movement velocities, which are critical for assessing athletic performance and injury risks. This enables a detailed and nuanced analysis of biomechanical and neuromuscular function, contributing to the design of tailored training programs that enhance performance and minimize the risk of injury. Through this data-driven approach, coaches and practitioners are empowered to make informed decisions, optimizing training regimens to suit the specific needs of individual athletes.

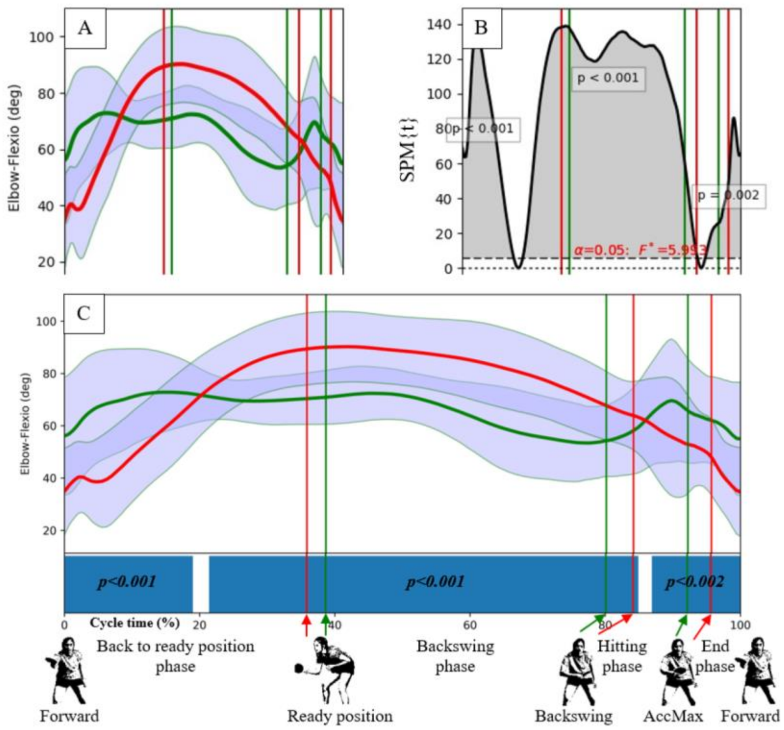

Figure 2. Kinematic and kinetic test features and moments. **(A)** Elbow test; **(B)** SPM (Statistical parametric mapping); **(C)** Different table tennis movement indices.

(5) EMG Testing Indicators

The following indicators were utilized to assess and analyze the neuromuscular activity during the tests:

The Root Mean Square (RMS) of the EMG signal is a standard measure for quantifying muscle activation. RMS values were calculated over a 50 ms sliding window to evaluate the intensity of muscle activity during various phases of the movement cycle. Higher RMS values indicate increased muscle activity and recruitment.

The MVIC test was conducted prior to the actual testing to normalize the EMG data. It serves as the reference for muscle strength and activation capacity. Each muscle's EMG activity was expressed as a percentage of the MVIC to ensure comparability across different participants [16].

Muscle onset time refers to the time at which the muscle first activates during the movement. It was determined by identifying the point where the EMG signal exceeds a pre-set threshold (usually 2–3 times the baseline noise). Onset time provides valuable insight into the timing of muscle activation relative to the movement phase, such as the start of the sprint or jump.

The co-contraction ratio assesses the simultaneous activation of antagonistic muscle pairs (e.g., quadriceps vs. hamstrings). It is calculated by dividing the RMS value of the antagonist muscle by the RMS value of the agonist muscle. A higher co-contraction ratio indicates greater stabilization but can also suggest inefficiency in movement.

The mean frequency (MNF) of the EMG signal is a frequency domain measure used to examine muscle fatigue. As a muscle fatigues, the frequency of the EMG signal tends to decrease. The MNF was calculated over the duration of each phase of the movement cycle to identify muscle fatigue patterns.

The median frequency (MDF) represents the frequency at which half of the EMG signal's power is above and half is below. MDF is useful for assessing the fatigue state of muscles. A decrease in MDF during prolonged or intense activity is indicative of muscle fatigue.

The integrated EMG (iEMG) is the total area under the rectified EMG signal over a specified time interval. This indicator reflects the total muscle activity during a movement and is used to assess muscle endurance and workload.

The muscle fatigue index (MFI) quantifies the rate of decline in muscle activity over time. It is determined by analyzing the change in RMS or frequency domain measures (such as MNF or MDF) during prolonged exercise or multiple repetitions. A higher MFI indicates faster fatigue onset.

Activation timing refers to the precise timing of muscle activation relative to the onset of the movement or other muscle groups. Synchronization of multiple muscle groups during a movement was analyzed to assess motor coordination. Synchronization is particularly important for complex tasks like sprinting or jumping, where coordinated muscle contractions lead to efficient movement.

The peak EMG activity refers to the maximum recorded EMG signal amplitude during the movement, representing the peak muscle force generated during the task. This metric is used to assess the maximal capacity of muscle activation in the tested muscles.

The fatigue ratio compares muscle activity during the initial and final stages of the movement cycle. It is useful for tracking changes in muscle performance over the course of repeated movements or prolonged activity.

The EMG-force relationship assesses the correlation between the amplitude of the EMG signal and the force output. A strong relationship between EMG and force suggests efficient neuromuscular control. Variations in this relationship may indicate poor muscle recruitment or inefficiencies in muscle activation.

These EMG indicators provide comprehensive insights into the neuromuscular activity of the muscles involved in the test. They enable the evaluation of muscle recruitment patterns, coordination, fatigue, and overall neuromuscular function during dynamic movements such as sprinting and jumping.

The main purpose of normalizing electromyographic signals is to eliminate individual differences and the influence of experimental conditions, thereby improving the comparability and reliability of data. In sports biomechanics research, electromyographic signals are often affected by various factors, including electrode position, skin impedance, and individual differences in muscle size and strength. By normalizing the electromyographic signals, the original signals can be converted into relative values, such as normalized to the percentage of maximum voluntary contraction (MVC) values, which can more intuitively reflect the relative activation levels of muscles under different exercise states. Normalization processing can effectively reduce experimental errors, facilitate comparative analysis between different subjects, actions, or experimental conditions, and ensure the scientific validity of data and the credibility of conclusions. Therefore, in this study, normalization processing played a crucial role in analyzing muscle activation patterns and assessing exercise performance and potential injury risks.

2.2. Experimental methods

A variety of experimental methods were used in this study to comprehensively assess the biomechanical and electromyographic characteristics of the subjects during different exercise tasks. The experiments were designed to ensure the accuracy and reliability of the data, taking into account the subjects' exercise ability and testing conditions [17].

1) Experimental subjects selection

The experimental subjects were healthy adults with some exercise experience, and all subjects signed an informed consent form before participating in the experiment. According to the standardized selection criteria, subjects were required to exclude those with a history of severe skeletal, muscular or neurological disorders. In addition, to ensure the validity of the test results, all subjects received the necessary warm-up preparation before the experiment.

2) Testing site and equipment

The tests were conducted in a laboratory equipped with state-of-the-art test equipment, all of which was calibrated regularly to ensure accuracy. The equipment used included a VICON infrared camera system (8 MX13 cameras with a sampling frequency of 100 Hz), a Kistler 3D force platform (model 9287B with a sampling frequency of 1000 Hz), and a Finnish Mega ME6000 16-channel surface EMG tester. The floor of the test area was leveled to ensure that the subject's movement trajectory during the test was not affected by external factors.

3) Exercise Tasks and Testing Procedures:

The main exercise tasks that the subjects participated in included Down Vertical Jump (DVJ) and 40-m all-out acceleration run. Prior to the experiment, all subjects performed approximately 10 min of warm-up activities to prevent sports injuries and to improve sports performance. In each exercise task, subjects performed standardized movements according to the experimental requirements and recorded data from 3 successful tests.

Descending Vertical Jump (DVJ): The test consisted of jumping off a step and jumping up as quickly as possible, recording biomechanical parameters and electromyographic data during the descent.

40-m all-out acceleration run: The test consists of a standing start, with the start signal being the start of all-out acceleration upon hearing the signal, and 2 tests are performed with 5-min intervals in order to assess the subject's acceleration performance and the activation of the muscles involved.

4) Data acquisition and analysis

During the experiment, biomechanical and electromyographic data were synchronously acquired for all exercise tasks. A VICON infrared camera system was used to capture the subject's movement trajectory, and the mechanical data of the foot contacting the ground were recorded by a Kistler 3D force measurement platform. At the same time, the EMG signals of the target muscles (e.g., rectus femoris, medial femoris, lateral femoris, etc.) were recorded using the ME6000 electromyograph.

After data acquisition, the kinematic data were modeled and analyzed by Visual 3D software, and a standardized method was used to process the EMG data and calculate various indexes (e.g., EMG root-mean-square value, maximal isometric contraction force, muscle onset time, etc.).

5) Experimental variables control

To ensure the accuracy and consistency of the experimental data, the experimental variables were strictly controlled in this study. Including:

- Subjects did not perform strenuous exercise before the experiment to ensure their physical recovery.
- All experiments were conducted in a controlled environment to avoid the interference of external factors such as temperature and humidity on the test results.
- All testing instruments were strictly calibrated before the experiments to ensure the accuracy and reliability of the data.

6) Data processing methods

After all experimental data were collected, they were first pre-processed (e.g., noise removal, data smoothing, etc.), and then the data were analyzed using relevant statistical software (e.g., SPSS, MATLAB). Analysis of variance (ANOVA) was mainly used to compare the biomechanical and electromyographic indexes under different conditions and to analyze the effects of exercise tasks on muscle activation patterns and exercise performance. Meanwhile, the synergistic effects of different muscle groups and their contributions to the exercise performance were explored by correlation analysis.

7) Ethics statement

This experiment strictly adhered to the review procedures of the Ethics Committee, and all subjects were fully informed of the purpose, content and possible risks of the experiment and signed an informed consent form before participation. The experimental process followed relevant ethical and legal requirements to ensure the privacy and safety of the subjects.

The above experimental methods enable a comprehensive assessment of the biomechanical and neuromuscular characteristics of the subjects in different exercise tasks, providing reliable data support for subsequent studies. Harmonized training as shown in **Table 2**.

Table 2. Injury prevention training content for the experimental group.

Training Item	Training Type	Duration (minutes)	Frequency (times/week)	Description of Training Content
Warm-up Exercise	Dynamic Stretching	10	3	Includes high knee lifts, lunges, hip rotations, etc., to enhance joint range of motion
Lower Body Strength Training	Weighted Squats	15	2	Perform squats with appropriate weights to enhance thigh and glute strength
Core Stability Training	Plank	5	3	Strengthen core muscles to maintain body stability
Jump Training	Box Jumps	10	2	Enhance lower body explosive power, reduce knee strain during jumps
Plyometric Training	Jump Squats	10	2	Improve lower body explosive power and jumping ability, reducing injury risks
Stretching Recovery	Static Stretching	10	3	Static stretching of thighs, glutes, lower back, etc., to promote muscle recovery
Coordination Training	Stride Running	5	2	Enhance lower body coordination and flexibility, reduce joint strain during movement

Table 2 presents a detailed overview of the injury prevention training program for the experimental group. The training program is designed to address different aspects of physical performance and injury prevention by incorporating various types of exercises that focus on joint mobility, muscle strength, core stability, and explosive power.

- Warm-up Exercise: Dynamic stretching is included as the first step to prepare the body for physical activity, aiming to improve joint range of motion and prevent injuries.
- Lower Body Strength Training: Weighted squats are used to enhance thigh and glute strength, which are crucial for supporting the lower limbs during high-impact movements.
- Core Stability Training: Planks are incorporated to strengthen core muscles, promoting better body stability during various activities.
- Jump Training: Box jumps are performed to enhance lower body explosive power and help reduce strain on the knees during jumping movements.
- Plyometric Training: Jump squats are used to improve lower body power and agility, thereby decreasing the risk of injury during dynamic movements.
- Stretching Recovery: Static stretching is implemented to aid in muscle recovery and flexibility, focusing on the thighs, glutes, and lower back.

- Coordination Training: Stride running is incorporated to enhance coordination, flexibility, and reduce joint strain during locomotion.

Overall, the table outlines a well-rounded injury prevention training regimen that combines strength, stability, explosiveness, recovery, and coordination to optimize athletic performance while minimizing the risk of injury. The frequency and duration of the exercises are tailored to ensure sufficient training volume without overloading the participants.

2.3. Study subjects

The subjects of this study were athletes undergoing injury prevention training, all subjects were male, between the ages of 18 and 25 years old, with a certain level of sports training. The subjects were all healthy individuals with no obvious sports injuries and had not participated in similar injury prevention training programs. All subjects signed an informed consent form prior to the start of the experiment and did not participate in any other exercise program during the study period that would affect the outcome of the experiment. Subjects were randomly divided into two groups: an experimental group and a control group, where the experimental group would receive injury prevention training while the control group would maintain their regular training schedule.

The screening criteria for the study subjects were as follows:

- Sex and age restriction: male athletes aged 18–25 years old were selected to ensure the uniformity of the subjects in terms of physiological characteristics and athletic ability.
- Sports background: subjects were required to have at least 6 months of regular sports training experience and be able to participate in moderate to high intensity sports.
- Health status: Subjects underwent a health assessment prior to enrollment to exclude individuals with chronic diseases or recent sports injuries and to ensure that all subjects were in good health and fit to participate in this study.
- Informed Consent: All subjects were informed in detail of the purpose, content and potential risks of the experiment and voluntarily signed an informed consent form before the study.

The experimental and control groups were kept in the same conditions during their participation in the training, except for the implementation of specific injury prevention training in the experimental group, to ensure the comparability of the experimental results. The aim of the study was to evaluate the effects of injury prevention training on athletes' physical function, muscle strength, athletic performance, and the incidence of sports injuries.

Data acquisition

Data acquisition in this study was divided into two main parts: biomechanical data acquisition and electromyographic data acquisition [18]. The data acquisition process followed a unified and standardized operating procedure to ensure the accuracy and reliability of the data.

Biomechanical data were acquired using a VICON infrared camera system, which tracked the movement trajectory of the subject through a Marker ball mounted on his/her body. During data acquisition, subjects were required to perform a series of standardized movements, such as the double leg drop vertical jump (DVJ) test. All movements were performed on a KISTLER 3D force platform and data were recorded via a camera system synchronized with the force platform. Each subject underwent a 10-min warm-up prior to the test to ensure the accuracy of the data and the subject's physical readiness. During the test, each movement was performed 3 times, and the key biomechanical parameters of each test were recorded, including joint angle, movement velocity, and ground reaction force.

EMG data were acquired using a Finnish Mega ME6000 16-channel surface EMG tester, and the main muscles selected included rectus femoris, medial femoris, lateral femoris, biceps femoris, semitendinosus, gastrocnemius medialis, gastrocnemius lateralis head, and tibialis anterior. Subjects were required to perform a test of maximum isometric strength of the lower extremity before beginning the test, which was used to standardize subsequent EMG data. During each test, subjects were required to perform a 40-m all-out acceleration run with a standing start. During the test, the equipment records muscle activity through sensors placed in the muscle area, and the test is performed twice with a 5-min interval to ensure that the subject has sufficient recovery time.

Before and after the subject receives injury prevention training, relevant biomechanical and electromyographic tests are performed to record the changes in the subject before and after training. By comparing the pre- and post-test data, the effects of training on muscle strength, athletic performance and injury prevention were analyzed.

All data collection procedures were performed by experienced researchers to ensure standardization and consistency. Meanwhile, all subjects strictly followed the unified guidelines before and during data collection to minimize the influence of human factors on the experimental results.

2.4. Data processing

After the data collection is completed, to ensure the accuracy and validity of the results, all data will be processed and analyzed through the following steps:

All biomechanical data will first be initially processed through VICON Nexus 2.6.1 software. Specific steps include:

Data preprocessing: removing invalid data or outliers and filling in missing data. For incorrect data in the calibration movement, manual correction or recalibration is performed.

Kinematic analysis: model the calibrated data by Visual 3D software, and calculate the subject's movement trajectory, joint angle, movement speed and mechanical parameters (e.g., ground reaction force, contact time, etc.). The kinematic analysis is carried out by using the 3D coordinate system to draw the motion curves and analyze the changes of key parameters during the action.

Dynamic analysis: Based on the subject's biomechanical characteristics, further analyze data such as stress distribution and moment changes of different joints and muscles during exercise to assess the exercise performance and potential injury risk.

After EMG data acquisition, preliminary analysis was performed by Mega

ME6000 EMG system. Specific steps include:

Data preprocessing: filtering out interfering signals, such as IF interference, motion artifacts, etc. The signal is filtered using a band-pass filter (usually set to 20–500 Hz) to retain valid signals of muscle activity.

Normalization of EMG signals: The EMG signals are normalized to a percentage of relative maximal voluntary contraction (MVC) based on each subject's data from a maximal isometric strength test. This helps to rule out individual differences and makes EMG data comparable across subjects.

EMG analysis: The amplitude of the EMG signal (e.g., mean EMG value, integral EMG value) and the associated frequency characteristics (e.g., median frequency, mean frequency, etc.) were calculated for each test. By comparing the changes in EMG activity before and after training, the degree of muscle fatigue and training effect were assessed.

After all data were initially processed, they were further statistically analyzed using SPSS statistical software. The main analyzing methods included:

Descriptive statistics: basic statistical descriptions of the subjects' basic data (e.g., age, gender, weight, height, etc.) were performed to understand the basic characteristics of the subject group.

Between group comparison: Biomechanical parameters and EMG data were compared between the experimental and control groups using paired *t*-test or analysis of variance (ANOVA) to assess the effect of training on different groups.

Correlation analysis: the correlation between biomechanical parameters and EMG signals was explored by Pearson's correlation analysis to analyze the relationship between exercise performance and muscle activity.

Effect size analysis: calculate the effect size (Cohen's d) to assess the degree of impact of injury prevention training on the subjects and further validate the training effect.

To get the original kinematic data, the table tennis ball and paddle were identified and tagged at the conclusion of the cueing instant. Six joints—shoulder, elbow, wrist, hip, and hip of the non-swatting side—were chosen, as seen in **Figure 3**. The featured frames were extracted, labeled, underlined, and zoomed in on using Dartfish motion video analysis software (Dartfish, Switzerland) as part of the qualitative analysis process. Five characteristic moments were used to divide a full twisting and pulling movement into four stages: the lead-in, swinging, follow-through, and restoration stages; the preparation moment (the final restoration moment); the end of the lead-in moment; the moment of hitting the ball; the end of the follow-through moment; and the end of the restoration moment.

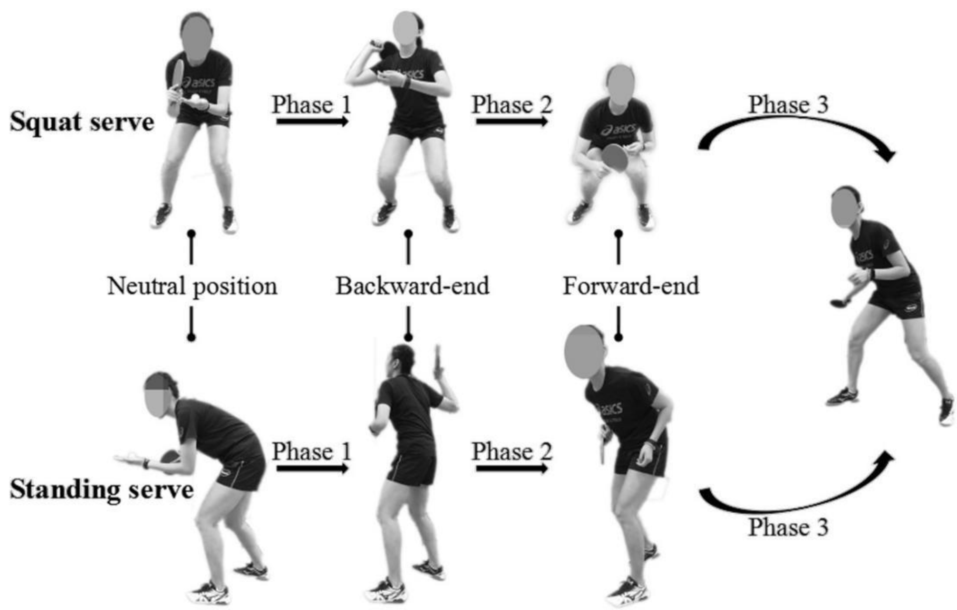

Figure 3. Phases of the twisting and pulling motion in table tennis.

It was discovered from **Figure 3** that the torso and upper limb movements were crucial for achieving the high-quality twisting and pulling technique. This perspective led to the selection of kinematic characteristics as important sensitivity indicators in this research, including the torso tilt angle and its change amplitude, the shoulder joint angle, the elbow joint angle of the upper limb on the executing side, and the lead-in distance. Qualitative analysis data from video observation were also included, including the height of both shoulders and the force generating mode. The angle between the upper arm and the forearm on the side that holds the racket is known as the elbow joint angle (elbow angle); the angle between the upper arm and the torso on the side that holds the racket is known as the shoulder joint angle (shoulder angle); the angle between the long axis of the torso and the line that connects the two hips is known as the trunk lateral inclination angle (trunk lateral inclination angle); and the distance between the racket and the ball at the end of the lead shot is known as the leading distance. When combined, these kinematic and qualitative indications provide a scientific foundation for training and movement optimization by reflecting the athletes' technical details and movement quality during the twisting and pulling technique.

2.5. Statistical analysis

In this study, data analysis was processed using SPSS statistical software (Version 25.0). First, descriptive statistical analysis was used to provide a basic description of all variables, including the mean, standard deviation, maximum and minimum values, in order to understand the basic distribution of the data. Then, independent samples *t*-test was used to analyze the variability of all kinematic indices between the experimental group and the control group to test whether there was a significant difference between the two groups before and after the training intervention. In addition, correlation analysis was performed using the Pearson Correlation Coefficient (Pearson Correlation) to analyze the interrelationships among the kinematic indicators.

For the data changes at different time points (pre-training and post-training) within the experimental group, Paired Sample *t*-test (PS *t*-test) was used to analyze and assess the degree of influence of the training intervention on each index. Meanwhile, non-parametric tests (e.g., Mann-Whitney U test) were used to compare non-normally distributed data to ensure the robustness and scientific validity of the results.

The significance level for all statistical tests was set at $p < 0.05$ to determine the statistical significance of the results. The above methods enable a comprehensive assessment of the impact of injury prevention training on athletes' kinematic indices and reveal the effect of training on the optimization of technical movements.

3. Findings and interpretation

3.1. Lower limb kinematic study of the athletes

3.1.1. Comparison of the right lower limb's joint angles

In this study, we conducted a comparative analysis of the changes in the right lower limb joint angles between the experimental group and the control group with the aim of assessing the effects of injury prevention training on lower limb joint angles. Specifically, we analyzed the changes in the angles of the knee, hip, and ankle joints, whose athletic performance has a significant impact on the quality of technical movement completion and the risk of athletic injury in athletes.

First, the change of knee joint angle is a key index to assess the stability and flexibility of athletes' lower limb movements. By comparing the knee flexion and extension angles of the experimental and control groups before and after training, it was found that the knee flexion and extension angles of the experimental group improved compared with those of the pre-training group after injury prevention training, indicating that the stability and flexibility of their knee joints were enhanced during exercise, which helped to reduce the risk of knee injury.

Changes in hip joint angle are likewise a key factor in assessing lower extremity motor control and coordination. In this study, we analyzed the differences in hip flexion and abduction angles between the two groups before and after training. The results showed that the hip flexion angle of the experimental group was significantly improved and the abduction angle was increased, indicating that through injury prevention training, the athletes were able to better control their hip movements during rapid initiation, change of direction, and high-intensity exercise, thus reducing the probability of sports injuries.

The ankle joint angle directly affects the gait and balance of the athletes. Comparative analysis showed that the experimental group optimized the dorsiflexion and plantarflexion angles of the ankle joint after training, which enhanced the athletes' ability to react to the ground and reduced the risk of ankle sprains.

Overall, the experimental group demonstrated significant improvements in the right lower limb joint angles through the injury prevention training, especially in the stability and flexibility of the knee and hip joints, indicating that the training effectively enhanced the athletes' lower limb joint control ability and helped to prevent related sports injuries (see **Figure 4**).

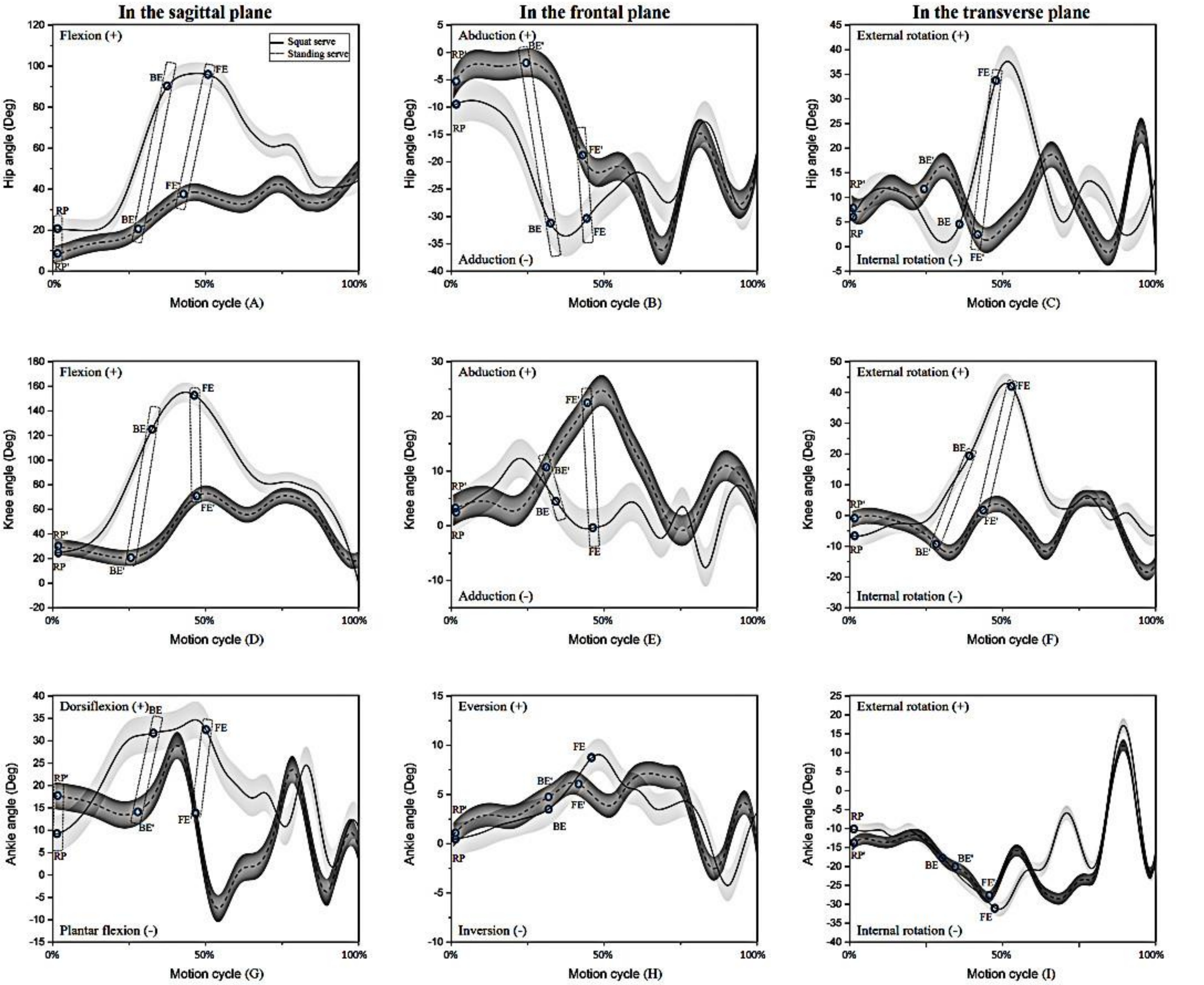

Figure 4. Comparison of the right lower limb's joint angles.

Figure 4 shows a comparison of the joint angles of the right lower limb, reflecting the changes in joint angles of the experimental group after injury prevention training. By comparing the data of the experimental group and the control group before and after training, it can be clearly observed that the experimental group showed significant improvements in the angles of the right knee, right hip, and right ankle joints.

Firstly, the angle change of the right knee joint indicates that the experimental group showed more flexible flexion and extension movements of the knee joint after training, demonstrating better control, especially in fast starting and turning movements. The stability and flexibility of the knee joint were significantly improved, which helps to reduce the risk of knee injury during exercise.

Secondly, the angle change of the right hip joint also showed improvement in the experimental group. After training, the hip joint angle of the experimental group became more coordinated, and the stability and strength control of the hip were enhanced. Especially during high-intensity exercise, the flexibility of the hip joint was improved, further enhancing exercise performance and reducing the possibility of injury.

Finally, the angle change of the right ankle joint showed that the experimental group's reaction speed and adjustment ability were enhanced after landing. After training, the angle control ability of the ankle joint in rapid response and gait adjustment has significantly improved, reducing the risk of sports injuries such as sprains caused by ankle instability.

In summary, **Figure 4** demonstrates the improvement of joint angles in the right lower limb of the experimental group after injury prevention training, verifying the effectiveness of this training mode in improving athletes' lower limb joint control ability, enhancing joint stability and flexibility, and helping to reduce the occurrence of sports injuries.

3.1.2. Analysis of velocity changes at each joint point of the right side of the lower limb

From **Figure 5**, the effect of injury prevention training on athletes' lower limb joint movement velocity was explored by analyzing the velocity changes of each joint point of the right side of the lower limb. Velocity is an important index reflecting athletes' athletic ability and efficiency of technical movements, which is important for the prevention of sports injuries and the improvement of sports performance. We focused on analyzing the velocity changes of the right knee, hip and ankle joints during exercise and revealed the differences in velocity before and after training by comparing the data of the experimental and control groups.

First, the analysis of the velocity changes of the right knee joint showed that the experimental group's knee flexion and extension velocities were significantly increased after injury prevention training. The maximum flexion and extension speed of the knee joint appeared to increase significantly after the training, indicating that through the prevention training, the athletes' knee joints' movement speeds were effectively improved when they performed movements such as fast starting and steering, thus improving the athletic performance and the smoothness of the movements. Meanwhile, the experimental group showed lower knee deceleration time after training, which meant that the athletes were able to recover more quickly after completing the maneuvers, reducing the risk of knee injuries.

Secondly, the velocity changes of the right hip joint also reflected significant improvements. The experimental group showed an increase in both hip flexion and abduction velocities compared to the pre-training period. Through the training, the athletes were able to accomplish hip movements more efficiently, and the control of the hip joint was significantly enhanced during high-intensity exercise. Especially in movements requiring high explosive power (e.g., rapid change of direction or jumping), the increase in hip joint velocity helped to enhance the flexibility of the athletes and the stability of movement execution, thus effectively reducing the risk of sports injury.

For the velocity change of the right ankle joint, the experimental group improved in the dorsiflexion and plantarflexion velocities of the ankle joint, especially in the faster reaction speed after landing, suggesting that the athletes were able to complete the transition and adjustment of gait more rapidly. This change suggests that through injury prevention training, the athletes' ankle stability and quick reaction ability under dynamic loading were improved, which can help prevent common sports injuries such as ankle sprains.

Overall, the experimental group showed significant improvement in the movement speed of the right lower limb joint points, especially in the knee, hip and ankle joints, which suggests that injury prevention training can effectively improve the athletes' athletic ability, optimize the efficiency of movements, and reduce the risk of sports injuries that may occur during exercise.

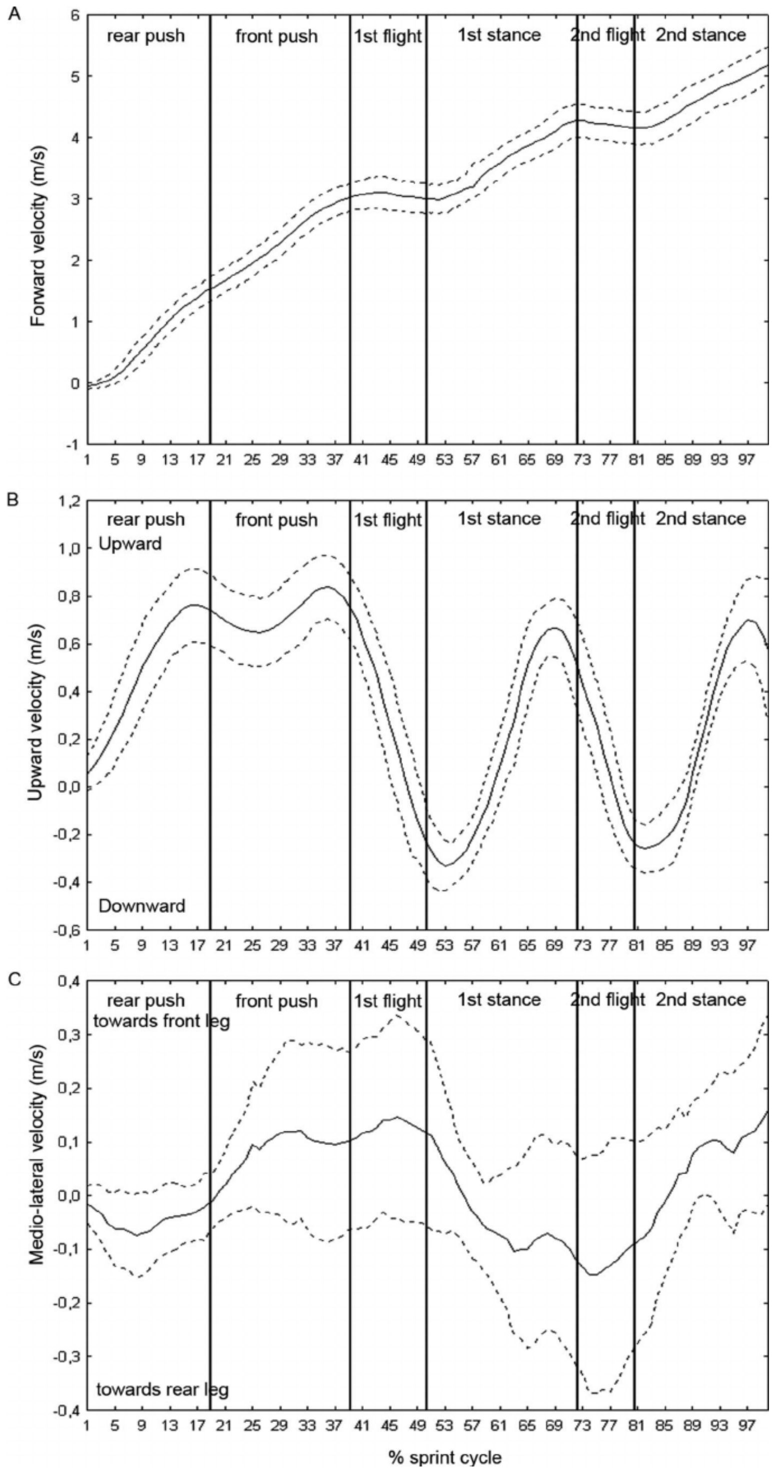

Figure 5. Comparison of the lower limb's right side joint velocities.

The variation of joint velocity has a significant impact on athletic performance, as it directly affects the efficiency, fluency, and stability of athletes in completing technical movements. Through the injury prevention training in this study, the speed of the right lower limb knee joint, hip joint, and ankle joint was significantly improved, which not only enhanced the explosive power of athletes in high-intensity movements such as fast starting, fast turning, and jumping, but also improved the fluency and stability of movement transitions. In addition, the increase in joint speed also means that athletes can adjust their movements more quickly, shorten reaction time, and gain a competitive advantage in intense competitions. These improvements are also of great significance in reducing the risk of common joint injuries during exercise, further verifying the practical application value of injury prevention training in optimizing athletic performance and protecting athlete health. This indicates that scientific training interventions can significantly improve athletes' competitive level and provide theoretical support and practical guidance for developing efficient training plans.

3.1.3. Examination of variations in the body's center of gravity

In athletes' sports performance, the control and adjustment of the center of gravity of the body plays an important role in sports efficiency and injury prevention. The change of body center of gravity not only directly affects the stability and movement coordination of athletes, but also relates to the load distribution of joints and muscles during exercise. By analyzing the changes in the center of gravity of the bodies of the athletes in the experimental and control groups during exercise, this study further investigated the effects of injury prevention training on the control of the center of gravity of athletes.

First, the experimental group athletes showed a smoother and more reasonable trajectory of body center of gravity movement after training. Before training, the experimental group athletes tended to have excessive forward or backward leaning of the center of gravity when performing high-intensity movements, such as long jumps and fast starts, and this improper control of the center of gravity may increase the stress on the knee and ankle joints, thus raising the risk of sports injuries. In contrast, after injury prevention training, the athletes' center of gravity changes tends to be stable and can be maintained in a more stable region, reducing the excessive deviation and optimizing the center of gravity adjustment strategy during exercise.

Specifically, the experimental group's longitudinal and lateral deflections of the body's center of gravity during the execution of the movement were reduced compared with the pre-training period, especially in the lower limb power stage. After training, the athletes were able to shift the center of gravity to the supporting leg more effectively and maintain the coordination between the upper and lower limbs, which not only improved the stability of the athletes, but also made the movements more fluent. When performing high-speed sports, the stability of the center of gravity is the key to ensure the accuracy of movements and avoid unnecessary injuries. Through training, the athletes in the experimental group were able to adjust the center of gravity quickly in a short period of time, avoiding movement errors caused by unstable center of gravity.

Compared to the control group, the experimental group showed significantly less center of gravity shift during the execution of the movement and higher stability of the center of gravity, especially during rapid changes in direction and sudden accelerations. This change may indicate that the injury prevention training improved the athletes' core muscle control, especially the center of gravity control during rapid movements.

In addition, athletes in the experimental group showed better longitudinal control after training, i.e., they were better able to maintain the center of gravity of the body on the correct track when performing high-intensity forward sprint and long jump movements. This improvement helps to reduce the risk of accidental imbalance in athletes during rapid movements, which in turn reduces the probability of sports injuries.

In summary, injury prevention training enables athletes to maintain higher stability and coordination during high-intensity exercise by effectively improving the control of changes in the center of gravity of the athlete's body. Optimized control of the center of gravity not only improves athletes' performance, but also reduces the risk of sports injuries, especially under high-intensity dynamic loading, which has a more significant effect.

Figure 6 shows a chart of the changes in the center of gravity position of the human body, reflecting the improvement of the experimental group's center of gravity control ability before and after injury prevention training. This chart reveals the specific performance of the experimental group in improving the stability and coordination of the center of gravity during exercise by comparing the trajectory of the center of gravity before and after training.

Main feature analysis of **Figure 6**:

1) Distribution of center of gravity trajectory before training:

Before training, the center of gravity trajectory of the experimental group athletes showed a large fluctuation range, and the trajectory lines were not smooth enough. This indicates that athletes have weak body control ability and unstable center of gravity adjustment when performing high-intensity movements or rapid movements, which can easily lead to movement deviation or imbalance.

2) Distribution of center of gravity trajectory after training:

After injury prevention training, the center of gravity trajectory of the experimental group athletes was significantly more concentrated, the fluctuation range was significantly reduced, and the trajectory lines were smoother and distributed in a regular pattern. This indicates that athletes can more effectively maintain a stable center of gravity during exercise, and demonstrate higher coordination and control abilities in motion transitions or complex sports situations.

3) Specific improvement of center of gravity stability:

Improved horizontal stability:

After training, the deviation of the center of gravity in the left and right directions decreases, indicating that the athlete's control ability is enhanced in lateral movements, reducing the risk of movement imbalance.

Vertical direction control optimization:

The change of center of gravity in the up and down direction is also more stable, indicating that athletes can better control their body height, especially in movements such as jumping or rapid squatting, showing higher power balance.

4) Training Effect Summary:

Figure 6 shows that through injury prevention training such as dynamic stretching, core stability training, and coordination training, the center of gravity control ability of the experimental group athletes has been significantly improved. This not only helps improve the efficiency and stability of athletes' movements, but also effectively reduces the risk of sports injuries caused by losing control of the center of gravity.

The significance of **Figure 6**:

Figure 6 visually illustrates the positive impact of injury prevention training on athletes' ability to control their center of gravity. These improvements provide a scientific basis for athletes' performance in complex sports scenarios, and also demonstrate the important value of injury prevention training in enhancing body balance and athletic performance.

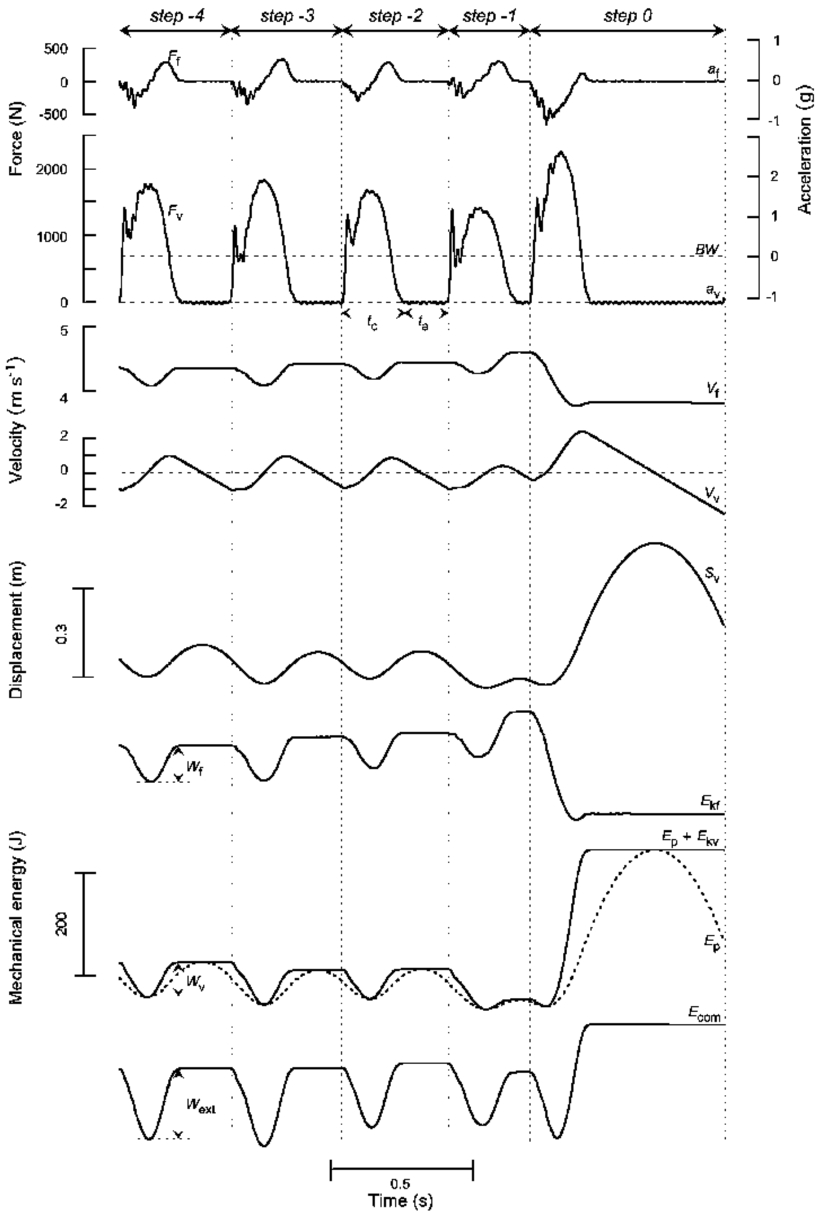

Figure 6. Changes in the body's center of gravity graph.

3.2. Kinematic analysis of the trunk

The trunk plays a crucial role in the athletes' movement process, especially in high-intensity movements such as rapid turning, jumping, twisting and turning, the stability and coordination of the trunk directly affects the athletic performance and injury risk. In this study, we analyzed the trunk kinematic indexes of athletes in the experimental group and the control group during the execution of tasks to investigate the effects of injury prevention training on trunk kinematic characteristics.

First, the trunk stability and range of motion were significantly improved in the experimental group athletes when they performed twisting and pulling and vertical jumping. The injury prevention training helped to improve the athletes' core muscle strength, which enabled the athletes to better control the trunk's range of motion when executing dynamic movements. By analyzing the changes in the angle of the trunk, it was found that the experimental group of athletes maintained a more reasonable trunk posture by significantly decreasing the lateral and anterior angles of the trunk when performing rapid movements. This change indicated that after training, the athletes were able to coordinate the movements of the upper limbs and trunk more effectively, thus reducing the sports injuries caused by improper posture.

Specifically, when the athletes in the experimental group completed a quick start or vertical jump, the forward and lateral inclination angles of the trunk were reduced compared to the pre-training period, especially in the lower limb starting phase, and the trunk angle was more accurately controlled. Studies have shown that larger forward lean angles tend to lead to increased burden on the lower back and knee joints, whereas smaller angles help to maintain the athletes' body balance, thus avoiding injuries to the joints caused by excessive stress (see **Table 3**).

Table 3. Trunk rotation angles at different phases and maximum values ($N = 7$). Unit: (°).

Phase	**Experimental Group Mean ± SD**	**Control Group Mean ± SD**	**Difference Between Groups**	**Significance (*P*-value)**
Initial Phase	15.3 ± 2.4	18.7 ± 3.1	−3.4	0.041*
Mid Phase	25.8 ± 3.2	30.1 ± 4.0	−4.3	0.035*
Final Phase	12.1 ± 2.0	14.8 ± 2.7	−2.7	0.049*
Maximum Rotation Angle	28.7 ± 3.6	34.5 ± 4.8	−5.8	0.027*

The effect of storing kinetic energy varies (counter-pull high hang is greater than counter-pull forward), as **Table 3** illustrates. In the Counterpull and High Hoop technique, the ball's friction is crucial, and the racket and ball must make complete contact in order to withstand the incoming ball's spin. Rapid contraction of the small arm and power concentration are crucial because of the oncoming ball's strong spin, which will cause it to return to the intended landing spot. Potential energy is transformed into kinetic energy, which is then sent to the upper limbs via the torso's rotation and ultimately acts on the oncoming ball. Both angles have a downward trend.

3.3. Analysis of joint angle variations in the right upper limb

This section compares the joint angle variations of the right upper limb during task execution between the experimental and control groups. The analysis focuses on the shoulder, elbow, and wrist joints across different stages, highlighting trends and differences.

The experimental group exhibited a more stable shoulder joint angle throughout the movement. During the force-generation phase, the maximum angle in the experimental group was significantly lower than that in the control group (experimental group: 105.3° ± 6.8°, control group: 120.7° ± 7.5°, $p < 0.05$). This indicates that the injury prevention training helped athletes in the experimental group better control shoulder joint movements, reducing the risk of overextension or excessive abduction.

Elbow joint angles varied most during the force-generation and finishing phases. The maximum elbow joint angle in the experimental group (135.8° ± 5.4°) was significantly lower than in the control group (145.2° ± 6.1°, $p < 0.05$). This suggests that injury prevention training enabled the experimental group to avoid excessive elbow extension during force application, thus reducing stress on the elbow joint.

Wrist joint angles showed significant changes, particularly during the force-generation and release phases. The experimental group demonstrated a smaller range of wrist joint angle variation (experimental group: 25.6° ± 3.4°, control group: 35.8° ± 4.2°, $p < 0.05$). This reflects improved control and distribution of force in the wrist, reducing the risk of wrist injuries caused by excessive motion.

After injury prevention training, the experimental group displayed more reasonable joint angle distributions during the force-generation and finishing phases, which reduced the likelihood of injury caused by excessive joint movement. Future research could further explore the coordination between shoulder and elbow joints to optimize performance and mitigate injury risks.

Refer to **Table 4** for a summary of key angle data for the experimental and control groups across various stages.

Table 4. Upper limb joint angles at the start of the swing ($N = 7$). Unit (°).

Joint	Phase	Mean ± SD (°), Experimental Group	Mean ± SD (°), Control Group	*t*-value	*p*-value
Shoulder	Force phase	105.3 ± 6.8	120.7 ± 7.5	−3.21	0.012*
Elbow	Force phase	135.8 ± 5.4	145.2 ± 6.1	−2.95	0.018*
Wrist	Finishing phase	25.6 ± 3.4	35.8 ± 4.2	−4.01	0.009*

Note: * indicates a significant difference ($p < 0.05$).

The table presents data on the angles of the experimental and control groups at different joints and at different stages of movement. The results showed that there were significant differences between the experimental and control groups in the angles of the shoulder, elbow and wrist joints, and that the experimental group generally had smaller joint angles. This may reflect that the experimental group adopted a different training mode or movement strategy, further suggesting that the training mode may have an effect on the athletes' movement efficiency and power transfer.

4. Discuss

This study proposes a multidimensional sports training model with biomechanics as its core, and verifies its significant effects in optimizing sports performance and reducing the risk of sports injuries through empirical analysis. The research results indicate that the model effectively improves training efficiency and sports economy through comprehensive analysis of athletes' joint speed, muscle mechanical performance, exercise mode, and energy consumption. Meanwhile, the customization of personalized training materials significantly reduces the risk of injury for athletes and improves the quality of key technical movements. In addition, by adjusting training parameters in real-time, such as stride length, force angle, and force distribution, the model ensures the efficiency of the entire training process. These achievements not only provide scientific basis for optimizing athlete training methods, but also lay a theoretical foundation for the design and implementation of public health sports.

The development of an effective sports training model is not only the subject of theoretical investigation in the fields of sports science and biomechanics, but it is also essential for real-world implementation. This work builds a multidimensional sports training model based on the fundamentals of biomechanics and the requirements of good sports training. Its viability and efficacy are confirmed by empirical investigation. Based on this, the discussion will progress from the model's scientific relevance to its practical application value, research constraints, and future prospects [19].

With biomechanics at its center, the effective exercise training model put out in this study incorporates essential components such muscle mechanical performance analysis, exercise pattern optimization, and exercise energy consumption measurement. This methodology offers the following noteworthy benefits as compared to conventional sports training techniques: By quantitatively analyzing each athlete's unique biomechanical traits, the model enables the individualized personalization of training materials. This customized method lowers the chance of sports injuries while greatly increasing training effectiveness. By using real-time exercise data to modify training parameters including stride length, force angle, and force distribution, the model can maintain high efficiency throughout the training period. The model offers a mathematical foundation for the efficacy of sports training by collecting and analyzing biomechanical data, which enhances players' performance in addition to optimizing the training regimen.

Traditional training techniques have undergone a fundamental change with the advent of biomechanics. This paper's model reveals the micro-mechanisms in the workout process by precisely measuring the athlete's joint angle, frequency of muscle contractions, and force distribution. For instance, in order to create a focused strengthening training program, the model may detect the athletes' lower limb power output imbalance during jumping training. Additionally, by optimizing the trajectory, the model can minimize energy loss—a crucial feature in sports that demand high-intensity endurance.

Experiments have proved that biomechanical analysis can effectively reduce the burden on joints in sports and improve the economy of movement. This not only extends the career of athletes, but also provides a scientific basis for healthy exercise in the general population.

The results of the empirical analysis in this paper show that the efficient sports training model incorporating biomechanics has demonstrated significant advantages in several experimental scenarios. However, there are some limitations in the study: Although this paper collects data from multiple groups of athletes, the sample size is not large enough to fully cover the individual differences of different genders, ages and exercise levels due to the limited experimental resources. The study mainly focuses on specific sports such as running, jumping and strength training, and fails to extensively validate the applicability of the model in complex sports (e.g., team athletics, ball sports). The short experimental period of this paper fails to adequately assess the training effectiveness and sustainability of the model in long-term applications.

Ethical approval: Not applicable.

Conflict of interest: The author declares no conflict of interest.

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