SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2024, 21(2), 412.
https://doi.org/10.62617/mcb.v21i2.412

Article

Injury prevention and rehabilitation strategies in physical education: A machine learning-based approach using biomechanical characteristics

Mingtao Wang*, **Zhen Pei**

School of Physical Education and Health, Xinxiang Vocational and Technical College, Xinxiang 453000, China
*** Corresponding author:** Mingtao Wang, wangmipz@163.com

CITATION

Wang M, Pei Z. Injury prevention and rehabilitation strategies in physical education: A machine learning-based approach using biomechanical characteristics. Molecular & Cellular Biomechanics. 2024; 21(2): 412. https://doi.org/10.62617/mcb.v21i2.412

ARTICLE INFO

Received: 18 September 2024
Accepted: 27 September 2024
Available online: 6 November 2024

Abstract: The field of sports biomechanics employs concepts from physics, biology, and engineering to investigate the mechanical characteristics of human motion and how they affect the body's anatomy and functions. With the development of technology, sports biomechanics has emerged as a crucial component of sports medicine, training, and rehabilitation. To reduce the risk of injury and enhance athletic performance, sports biomechanics examines motions in sports in great length. The purpose of the study is to establish injury prevention and rehabilitation strategies for physical education (PE) teaching based on biomechanical characteristics. The early warning mode of sports injuries is recognized using advanced deep learning (DL) techniques, specifically resilient convolutional neural networks (RCNN). Biomechanical data from wearable sensors is used in this study to find trends related to sports-related injuries. A questionnaire survey of 228 students from various colleges was conducted. Individualized rehabilitation strategies will be provided to injured participants, taking into account their unique biomechanical deficiencies. These programs will be created in conjunction with physical therapists, and they will be updated in response to the patient's progress toward recovery. The study found that their sports injuries were acute and chronic. This research demonstrated the treatment, prevention, and rehabilitation strategies of injuries in sports. The study emphasizes that biomechanical analysis is crucial for improving PE programs, which will eventually enhance students' performance and overall health.

Keywords: physical education (PE); injury prevention; rehabilitation strategies; biomechanical characteristics; resilient convolutional neural network (RCNN)

1. Introduction

The personalized PE teaching plan in sports constitutes a specialized strategy that addresses every student's requirement, talents, and goals [1]. This customized approach considers variables like level of physical fitness, style of learning, and unique interests, which ensure that every student gets targeted education instruction and assistance [2]. This strategy intends to increase engagement among students, performance, and a positive learning environment through the utilization of adaptive tactics and individualized feedback [3]. The plan could consist of personalized exercises, developing skills activities, and evaluations that are appropriate for the student's developmental stage as well as their personal goals, eventually fostering a better efficient, and well as enjoyable educational experience in sports.

Injury prevention in sports includes an important part of athletic performance and training that aims to reduce injury risk and improve overall safety [4]. This entails applying a complete strategy involving adequate warm-up as well as cool-down routines, training of flexibility and strength, technique efficiency, and the proper utilization of protection equipment [5]. Regular physical evaluations to detect and resolve any possible vulnerabilities, as well as instruction on injury risks along with secure procedures, are all essential parts. By proactively tackling these characteristics, athletes could decrease their injury risk, as well as increase their lifespan in sports, and manage their peak performance standards [6].

Rehabilitation tactics in sports serve as essential for regaining an athlete’s functioning and performance following injuries, accidents, or surgeries [7]. These tactics include a complete technique that involves an initial examination, managing pain, physical rehabilitation, and a progressive return-to-play plan. Personalized training routines to improve flexibility, endurance, and strength are common, as are sport-specific drills to restore skill abilities and confidence. Furthermore, psychological help can be crucial for addressing the mental as well as emotional obstacles of rehabilitation [8]. Efficient rehabilitation strives to heal but also to avoid future injuries through enhancing the biomechanical effectiveness and resolving any fundamental concerns.

The characteristics of biomechanics in sports are concerned with the mechanical fundamentals that regulate human motion and their effectiveness. This domain explores how forces like friction, gravity, and physical exertion influence an athlete’s mobility and performance. Biomechanics gives perspectives on optimizing the technique, improving performance, and reducing injury risk by analyzing factors such as muscle contractions, joint angles, and also body alignment [9,10]. Comprehending these traits enables the establishment of specialized training programs as well as equipment designs that could increase athletic performance outcomes and assist the entire physical health in various kinds of sports activities [11].

Figure 1 displays the personalized PE plan focused on injury prevention and rehabilitation strategies. In the center of the image is biomechanical analysis which includes the human performing a movement and the pink colored circle dots indicate the areas prone to injury. Personalization and assessment are surrounded by humans. It includes motion capture (camera, sensor), wearable sensors (wearable watch and sensor), and data analysis (biomechanical data). The left side of the image contains injury prevention, which includes warm-up exercises (stretching, warming up), strengthening exercises (lifting weights, doing balance exercises), and balance training (balance board, performing stability exercises). The biomechanical analysis points to injury prevention. The right side of the image contains rehabilitation strategies, which include corrective exercises (therapy exercises), physical therapy (therapist working with an athlete, resistance band exercise), and recovery stages (muscle massage, performing on the thread mill). The biomechanical analysis points to the rehabilitation strategies. The arrow from injury prevention to biomechanical analysis is denoted as continuous assessment. The arrow from rehabilitation strategies to biomechanical analysis is denoted as plan adjustment.

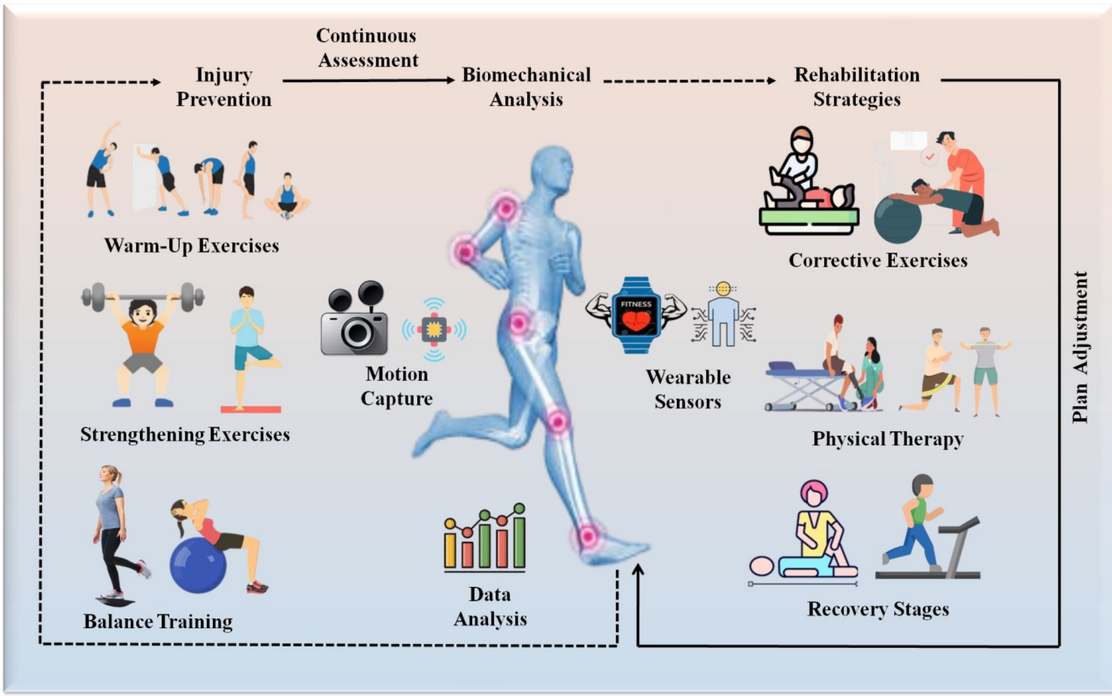

Figure 1. Personalized physical education: Injury prevention and rehabilitation.

A tailored PE teaching approach emphasizes injury prevention and recovery by examining every student's biomechanical features. This method entails comprehending their anatomical and physiological characteristics, like muscle strength, joint alignment, as well as movement patterns, to develop individualized training routines and preventative therapies. This individualized approach assures that PE programs are better considerate of students' different requirements, as well as promoting for a long-time health and athletic performance effectiveness while decreasing the injury risk.

The main objective of this research is to develop injury prevention and rehabilitation strategies for PE teaching based on biomechanical characteristics.

Key contribution of this research

- The present research develops injury prevention and rehabilitation strategies for PE teaching based on biomechanical characteristics.
- This research uses a mixed-methods approach. Initially collected the participant's data.
- After that, utilizing the deep learning (DL) approach such as Resilient Convolutional Neural Network (RCNN) and the statistical analysis.
- Finally, analyze the results of this research.

The organization of the present research is as follows: The literature review is represented in section 2. Section 3 provides a detailed explanation of materials and methods. The results of this study are illustrated in section 4. The conclusion has been demonstrated in section 5.

2. Literature review

Tee et al. [12] provide a primary goal on sport injury prevention has practitioner's pertinent and helpful data to aid their decision-making regarding in localized injury prevention practices. The article has contained injury prevent at real-world responsive in different framing. Li [13] provided a complete comprehension of the present state of rehabilitative sports, especially basketball players' injuries to the ankle. Then, the impact of sports recovery on players was discussed from basketball injuries in the ankle through the insight of sports medicine incorporation and offered contemporary social progress and technical advances.

The clinical commentary is explored [14] every one of these three problems in the sports shoulders, assisting the professional with preventing the injury; offering evidence-based practice therapy, and guiding the athlete toward return-to-play (RTP). O'Brien et al. [15] assessed the real-world creation and execution of individualized injury prevention exercise programs (IPEPs) among academy-based soccer players. Liu [16] investigated the complex impact of coaches in preventing injuries as well as talent retention among young athletes. The article discovered critical factors such as incorporating injury prevention into training routines, leveraging available resources, overcoming opposition to alteration, and encouraging personalized athlete participation.

Kozin et al. [17] determined the impact of neuromuscular training combined with a learning program on the injury possibility for students as rock climbers, and future professionals in the domains of PE as well as sports. The created neuromuscular training program, in combination with exercises that utilize a closed kinematic chain as well as an educational program, could be suggested to injury-preventive students as rock climbers learn under PE along with sports. Wei and Yalong [18] employed the biomechanical analysis approach to assess the alterations of information throughout the final exertion phase and the related reasons. The study found that an injured constituent ratio of fifty national as well as elite javelin-throwing athletes had been examined. Lu [19] investigated the characteristics and causes of ankle joint injuries in basketball players, offered advice on how to manage them, and suggested ways to avoid them in the future. To expand the investigation method of ankle joint injuries, data mining techniques have been used to examine the investigation method of ankle joint damage. Vincent et al. [20] demonstrated the most recent integrated data on musculoskeletal injuries associated with trail running, as well as treatment strategies for injury prevention and advancing safe involvement.

Zhihong [21] investigated how individualized treatment and technology could improve sports performance while reducing injury risk. The approach utilized technology with personalized treatment to help the athletes heal faster and avoid injuries. de Freitas et al. [22] discovered injury prevention tactics and procedures used by Brazilian soccer clubs. The majority of Brazilian soccer teams had preventative initiatives; however, few are based on scientific data. The physiotherapist becomes a highly active practitioner. Injury risk variables, evaluation methodologies, and preventative training remained similar across all teams assessed.

An objective optimization model was developed to enhance the science level in collegiate athletes' training through integrated particle swarm optimization (PSO) [23], and use the Kriging agent model to enhance the calculation process. It allowed to create the best possible training plan for college athletes. Evaluated the changes in physical fitness stages of students with varying fitness levels after they received different Individualized PE Plans (IPEPs) [24] by creating an intelligent PE platform and an adaptive fitness enhancement model (AFEM) based on senseless exercise behaviors monitoring (EBM) technology. 400 undergraduate students participated, and they were randomly assigned to one control group and four experimental groups. Yuan [25] explored the strategies used in school PE classes for training track and field athletes. It analyzed the benefits, state, and challenges of track and field education, and offered creative suggestions for instruction and training. The objective is to enhance students' physical abilities and improve the effectiveness of track and field teaching in schools. An artificial intelligence (AI) powered model [26] that enhanced injury management by deliberate scheduling of rest periods during the phases of athletes' recovery. By using data analytics to continuously monitor athletes' health, the notion gives sports managers a prediction tool for a proactive and preventative approach to injury management. It looked at health and performance data from athletes in different sports using advanced machine learning techniques to identify patterns in training schedules, treatment philosophies, and the consequent risk and severity of injuries.

The use of online teaching methods in college PE courses, focuses on their benefits, challenges, and integrated modular curriculum designs was explored by Zhai [27]. It also discussed the architecture of online learning platforms and the creation of instructional materials based on sports biomechanics and psychology.

3. Materials and methods

Research investigation uses a mixed-methods approach to create and assess personalized injury prevention along with the rehabilitation tactics in PE utilizing the biomechanical analysis and DL approaches. **Figure 2** provides a flow diagram outlining the research methodology, including participants, biomechanical data collection (wearable sensors and data acquisition), deep learning (RCNN and injury detection), survey questionnaires (design and data collection), rehabilitation strategy development, and statistical analysis. The study, conducted with 228 college students engaged in PE programs, utilized wearable sensors to capture biomechanical data, focusing on acceleration, angular velocity, and joint stress. This data was analyzed using a Resilient Convolutional Neural Network (RCNN) to predict potential sports injuries. Additionally, a survey was administered to collect information on injury history, PE experience, and perceived effectiveness of rehabilitation tactics. Based on biomechanical findings, personalized rehabilitation programs were designed and continuously updated, incorporating cross-disciplinary collaboration among sports scientists, physical therapists, and trainers. The strategies involved detailed recovery timelines, functional testing (e.g., balance, and strength assessments), and criteria for safely returning to physical activities.

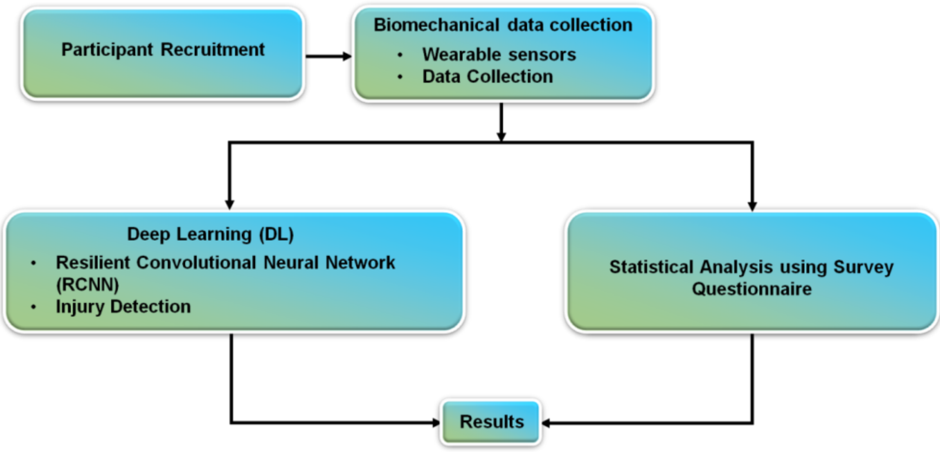

Figure 2. Proposed flow diagram.

3.1. Participants

An entire sample of 228 students from different colleges took part in the research. Participants have been chosen depending on their engagement in PE initiatives as well as their willingness to participate in the research. **Table 1** shows the selection criteria and demographic data.

Table 1. Selection criteria and demographic data.

Criteria	
Inclusion criteria	Students registered in PE initiatives agreed to be involved in both biomechanical data collecting and a questionnaire survey.
Exclusion criteria	Students who have severe pre-existing medical illnesses or any other disabilities that could hinder them from participating in physical activities have been excluded to assure their safety and relevance to the research's focus.
Demographic information	
Age group	The study participants ranged from 18–25 years
Gender distribution	The samples included in students are male 114 and female 114
Physical activity levels	Participants were divided into 3 activity levels. They are sedentary, moderately active, and extremely active, to investigate the influence of physical activity on the risk of injuries along with rehabilitation.

Participants have been recruited through the announcements and brochures distributed at their respective college institutions. Those interested participants have been assessed for eligibility.

3.2. Biomechanical data collection

3.2.1. Wearable sensors

- Sensors have been calibrated before data collection, to assure accuracy. Calibration entailed adjusting the sensor's settings to know the standards and validating the readings. In addition, frequent validation checks were carried out during the research process to maintain the data accuracy.
- The research investigation used a variety of wearable sensors that captured the biomechanical data, such as accelerometers, gyroscopes, and force sensors. Accelerometers are used to measure the linear acceleration in all 3 dimensions ($x, y,$ and z) and evaluate the movement dynamics. Gyroscopes are utilized to

capture the angular velocity around several axes along with assessing the rotational motions. Force sensors are employed to assess joint stress as well as forces during physical activity.

- The sensors have been strategically placed on participants to track the pertinent biomechanical characteristics. Accelerometers have been attached to the wrists, ankles, and torso to collect information about entire movements and accelerations. Gyroscopes have been positioned in similar positions to assess the rotational motions and joint angles. Force sensors have been placed on major joints (for example, knees and elbows) to track the forces experienced during the activities.

3.2.2. Data acquisition

- Monitoring Activities include the data that have been gathered throughout various kinds of physical activities representative of regular sports and exercise routines such as running, jumping, and strength exercises. Running is to examine the impact forces, gait patterns, and entire motion dynamics. Jumping is to evaluate the landing impact, vertical forces, as well as joint stress. Strength exercises are to assess the forces along with the joint angles throughout lifting with resistance.
- Data Collection Protocol: Participants wear the sensors while engaging in routine physical activities along with particular exercises intended to replicate the common sporting motions. Data has been recorded constantly or during predetermined intervals, based on the activities and sensor types.
- The included data parameters are acceleration, angular velocity, and joint stress. Acceleration is expressed in meters per second squared (m/s^2) and indicates the alterations in speed and direction. Angular velocity can be assessed in degrees per second ($°/s$) and represents rotational speed around the joints. Joint Stress is calculated in Newton's (N) and represents the force implemented to joints throughout the activities.

3.3. Deep learning (DL)

In this study, DL is used to assess the biomechanical data to predict sports injuries. Through implementing the DL technique to sensor data, the purpose is to recognize the patterns that indicate possible injuries, which allows for prompt intervention and individualized rehabilitation tactics.

3.3.1. Resilient convolutional neural network (RCNN)

The purpose of RCNN is to identify patterns in the biomechanical data to forecast sports injuries and enhance the prevention of injuries, as well as provide personalized rehabilitation tactics. The RCNN approach, which consists of a convolutional layer, pooling layer, fully connected layer, and softmax layer has been designed to identify the patterns and anomalies indicative of possible sports injuries.

- Convolutional layer

It contains feature maps such as depth slices along with every feature map including collections of neurons. Equation (1) provides the outcome of the convolution process in the convolutional layer. Where E indicates the kernel (filter) dimension, n denotes feature maps, A represents bias, and X_i indicates kernel weight.

The convolutional layer outcome is represented as z_j^k, where j signifies the j^{th} feature map within a layer designated by k.

$$z_j^k = A_j^1 + \sum_{i=1}^{n_1(1-1)} E_{j,i^k} \times X_i^{(k-1)} \tag{1}$$

- Pooling layer

To reduce the quantity of variables and network computations, the pooling layer is typically utilized between the convolutional layers. As a consequence, using the sub-sampling function, the input dimension is reduced in every depth division, preventing over-fitting during network training. Because the input spatial dimension is reduced through the pooling procedure, and the depth size has not altered. The output height and width are accomplished in the pooling layer using Equations (2) and (3). Where X_1 represents the input's width, G_1 represents the input's height, T denotes the stride dimension, and E indicates the kernel dimension.

$$X_2 = \left(\frac{X_1 + E}{T}\right) + 1 \tag{2}$$

$$G_2 = \left(\frac{G_1 + E}{T}\right) + 1 \tag{3}$$

- Fully connected layer

The final layer of the framework represents a completely interconnected layer. All of the neurons in the completely linked layer are connected to all of the neurons in the layer before it. Equation (4) provides the fully connected procedures, with k and $(k-1)$ representing fully linked layers. The j^{th} unit in layer k represents the outcome of the final fully linked z_j^k. Layer k contains feature maps of $n_1^{(k-1)}$ through $n_2^{(k-1)} \times n_3^{(k-1)}$dimensions that are specified as inputs. $X_{j,i,q,t}^k$ represent the weighted relations of the j^{th} unit in layer k as well as Z_j, which is indicated as the i^{th} layer unit$(k-1)$ in the (q,t) position.

$$z_j^k = e\left(z_j^k\right)\text{with}z_j^k = \sum_{i=1}^{n_1^{(k-1)}} \sum_{q=1}^{n_2^{(k-1)}} \sum_{t=1}^{n_3^{(k-1)}} X_{j,i,q,t}^k \left(z_i^{k-1}\right)_{q,t} z_j^k = A_j^1 + \sum_{i=1}^{n_1(1-1)} E_{j,i^k} \times X_i^{(k-1)} \tag{4}$$

- Softmax layer

In general, during the final layer of the framework, the soft max function has been employed to determine the possibility of every ground truth label of outcomes from $0\ to\ 1$, and the value of the outcome is converted to a perceptible value. Equation (5) defines the softmax function. In this equation, l denotes the size of randomized values (y), which are transformed into significant values from zero to one through the softmax function $e(y)$.

$$e(y)_j = \frac{f^{y_i}}{\sum_{l=1}^{l} f^{y_l}}\ for\ i = 1, \ldots, l \tag{5}$$

The RCNN features to assist the network in detecting the patterns as well as anomalies related to probable injuries. The RCNN's resilience functions improve its capability to manage the data, which leads to higher accuracy in recognizing injury-related patterns. Through training, the RCNN develops the ability to recognize the earlier warning symptoms of injury, which allows prompt intervention as well as the establishment of individualized rehabilitation techniques. RCNN accurately detects injury risks, which guides personalized rehabilitation strategies and improves PE efficiency.

3.3.2. Injury detection

The capacity of the RCNN to discern aberrant trends and patterns in biomechanical data allows for injury identification. The model's predictions can be utilized to identify prospective injuries, which allows for early interventions as well as the establishment of personalized rehabilitation programs. The model's efficiency in predicting the injury risks is evaluated using performance measures such as accuracy, precision, recall, and F1-score.

- Accuracy: It assesses the entire accuracy of the RCNN approach for predicting the injuries. It concludes that the higher accuracy demonstrates the model's efficiency in properly detecting injury instances.
- Precision: It determines the percentage of accurate injury predictions amongst every positive forecast. Findings are highly precise and assure that the technique injury forecasts are accurate while limiting false positives.
- Recall: It assesses the capability of the model to recognize the actual injuries. It concludes that the significant recall indicates that the model efficiently recognizes the majority of injury instances.
- F1-score: It provides a balanced performance metric by combining recall and precision. Outcomes are substantial F1-score suggests that the model is mostly efficient overall at properly recognizing the injuries as well as balancing false negatives and positives.

3.4. Survey questionnaire

- Survey design

To collect the students' data based on injury history, PE experience, and perceived effectiveness, which will be correlated with biomechanical information to measure the efficiency of personalized injury prevention along with rehabilitation techniques. The structure of the survey questionnaire is represented in **Table 2**.

Table 2. Structure of survey questionnaire.

Characteristics	Details
Demographic information	Age, gender, academic year, and physical activity level
Injury history	Details are based on the frequency, severity of injuries experienced, and type, such as acute or chronic.
PE experience	Physical activity types and frequencies, as well as satisfaction with present PE programs.
Perceived effectiveness	Opinions on the efficiency of injury prevention along with rehabilitation tactics utilized throughout the research.

- Data collection

The questionnaire is conducted virtually using a secure internet platform.

Participants received accessibility to the survey questionnaire link and comprehensive instructions. There were 250 surveys distributed. 228 completed the survey questionnaires had been returned accomplishing a 91.2 percent response rate.

3.5. Development of rehabilitation strategy

Rehabilitation strategy development includes personalized programs and program updates. **Table 3** represents the personalized programs and program updates. Personalized rehabilitation programs are based on biomechanical deficiencies, injury type, physical and functional goals, recovery time, monitoring, and adjustment. Rehabilitation program updates contain program monitoring, program adjustments, functional testing, and criteria for return to activity. Rehabilitation programs are regularly updated depending on feedback and progress.

Table 3. Personalized programs and program updates.

Personalized programs	
Factor	**Details**
Biomechanical deficiencies	Recognized using the RCNN technique. Concentrate on addressing problems such as joint instability and inappropriate force distribution.
Injury type	Acute injuries require rest and conservative treatment in the early stages. Treat chronic injuries by correcting repetitive motion dysfunctions.
Physical and functional goals	Range of motion (ROM) activities include dynamic stretching as well as passive ROM. Strength and stability exercises including resistance and proprioception. Coordination drills and balance exercises for neuromuscular control.
Recovery time	The duration ranges from four to twelve weeks. Progressively increasing the exercise intensity.
Monitoring and adjustment	Objective metrics include biomechanical examinations (for example joint angles and motion effectiveness). Subjective Feedback is provided Weekly assessments of pain levels and workout difficulties.
Program updates	
Factor	**Details**
Program monitoring	Objective metrics have been gathered using the wearable sensors. Subjective feedback includes weekly assessments of progress and workout difficulties.
Program adjustments	Enhancing intensity refers to the difficulty of exercise increases gradually. Injury Specificity refers to the adjustments depending on the participant's advancement and weak areas. Coordination between sports scientists, physical therapists, and trainers is referred to as cross-disciplinary engagement.
Functional testing	Balance and agility drills include single-leg balance tests and agility ladder drills. Strength assessment using isokinetic dynamometry. Performance measures include sport-specific movement testing.
Criteria for return to activity	Complete recovery based on evidence of enhanced biomechanics and pain-free condition. Gradual reintegration begins with lower-impact activities and develops as allowed.

3.6. Statistical analysis

Statistical analysis is implemented to assess the model performance and establish the efficacy of injury prevention and rehabilitation tactics. The present investigation uses the statistical tool SPSS Statistics version 28.0. The statistical techniques are descriptive statistics, correlation analysis, and regression analysis.

4. Results

The research aims to assess personalized injury prevention and rehabilitation tactics in PE utilizing biomechanical analysis and DL approaches. Identifying the injury detection performance utilizing the RCNN, survey outcomes, statistical analysis outcomes, and assessment of pre- and post-rehabilitation are all included. The significance $\rho -$ value of this research is ≤ 0.05.

4.1. Injury detection performance using RCNN

Table 4 and **Figure 3** show the RCNN performance. The outcomes of RCNN are 92 % in accuracy, 89 % in precision, 90% in recall, and 89.5% in f1-score. In the performance of injury detection, RCNN provides superior outcomes. **Table 4** presents the numerical outcomes of the RCNN model's performance. The accuracy reached 92%, indicating a high level of correctness in predictions. Precision stood at 89%, reflecting the model's effectiveness in identifying true positives. The recall value was 90%, signifying the model's ability to capture relevant cases. The F1-Score, balancing precision and recall, was 89.5%, underscoring the overall performance of the model.

Table 4. Numerical outcomes of RCNN performance.

Metrics	Value (%)
Accuracy	92
Precision	89
Recall	90
F1-Score	89.5

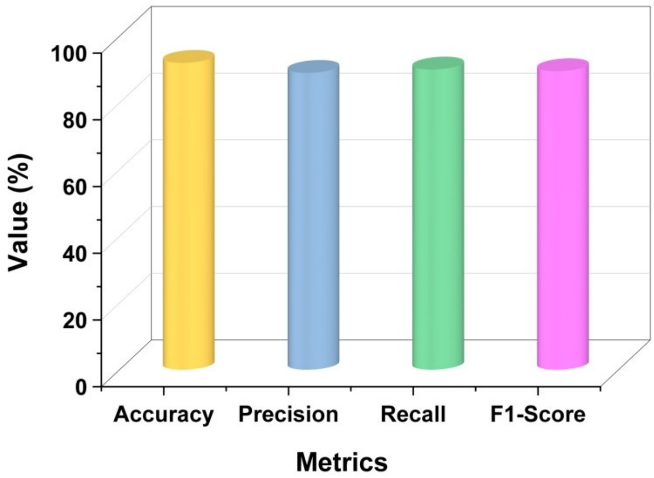

Figure 3. Graphical representation of RCNN performance.

4.2. Outcomes of the survey

The survey outcomes include injury type outcome and rehabilitation program effectiveness.

4.2.1. Types of injury

Table 5 shows the injury types based on the survey outcomes. Acute and chronic injuries. The number of cases of acute injuries is 65 (28.5%), and the number of cases of chronic injuries is 163 (71.5%). **Table 5** presents the survey outcomes on injury types, distinguishing between acute and chronic injuries. Acute injuries accounted for 65 cases, representing 28.5% of the total, while chronic injuries were more prevalent, with 163 cases, making up 71.5% of the surveyed injuries. The data highlights the higher occurrence of chronic injuries compared to acute ones. This suggests that long-term, repetitive strain might be a more significant issue for the surveyed population. The percentages underscore the disparity between the two injury types.

Table 5. Survey outcomes of injury types.

Injury Type	Number of Cases	Percentage (%)
Acute Injuries	65	28.5
Chronic Injuries	163	71.5

4.2.2. Rehabilitation programs effectiveness

The purpose is to assess the influence of tailored rehabilitation programs on participants' recovery, enhancement of performance, and satisfaction. Participants evaluated the personalized rehabilitation program's efficiency using an established survey. Several criteria were used to assess the effectiveness which includes improved physical performance, a decrease in injury signs, and the entire program's satisfaction. **Figure 4** shows the survey results. The findings of high effectiveness level are 49.1% (number of responses = 112) in very effective, 38.2% (number of responses = 87) ineffective, 8.8% (number of responses = 20) in neutral, and 3.9% (number of responses = 9) in ineffective. It concludes that personalized rehabilitation programs substantially enhanced rehabilitation and effectiveness, with higher satisfaction among participants and efficacy across various kinds of injury types.

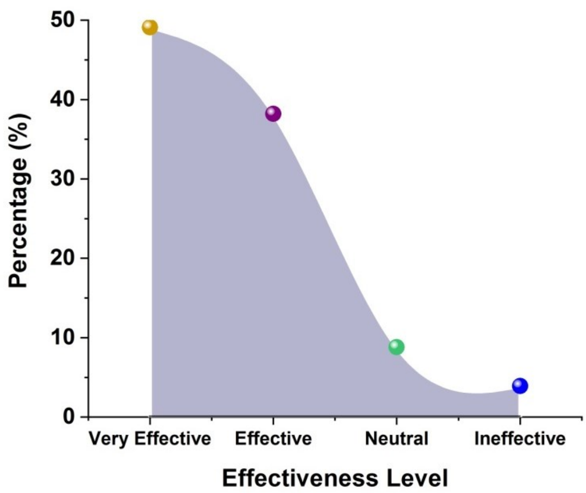

Figure 4. Effectiveness of rehabilitation programs.

4.3. Outcomes of statistical analysis

The statistical analysis outcomes include descriptive statistics, correlation analysis, and regression analysis. The biomedical parameters are acceleration, angular velocity, and joint stress.

4.3.1. Descriptive statistics

The purpose of descriptive statistics is to characterize the main tendency and variability of biomechanical parameters, which assists in comprehending the entire trend in the gathered data. **Table 6** provides a comprehensive overview of the descriptive statistics for key biomechanical parameters, offering valuable insights into the central tendencies and variability of these measurements. The mean value represents the average measurement for each biomechanical parameter, while the standard deviation indicates the extent of variability or dispersion within the dataset. Specifically, the outcomes include acceleration (mean = 1.23 m/s^2, standard deviation = 0.45 m/s^2), angular velocity (mean = 4.56 °/s, standard deviation = 1.23 °/s), and joint stress (mean = 85.4 N, standard deviation = 22.8 N). These descriptive statistics not only summarize the typical values observed across the sample but also provide important information about the spread of the data. A lower standard deviation reflects consistency in measurements, while a higher standard deviation indicates greater variability, which could suggest differing biomechanical responses under varying conditions. This information is critical for assessing the risk of injury, as it helps identify patterns or outliers that may contribute to excessive strain or stress on joints, muscles, or tissues. By understanding the variability and central tendencies, researchers and clinicians can develop more precise injury prevention strategies, design ergonomic interventions, and optimize rehabilitation programs to reduce biomechanical stress and improve overall movement efficiency.

Table 6. Descriptive statistics for biomedical parameters.

Parameter	**Unit**	**Mean $\bar{X}$**	**Standard Deviation ($\boldsymbol{\sigma}$)**
Acceleration	(m/s^2)	1.23	0.45
Angular Velocity	$(°/s)$	4.56	1.23
Joint Stress	(N)	85.4	22.8

4.3.2. Correlation analysis

Correlation Analysis' purpose is to establish connections between biomechanical parameters as well as entire injury risk and also to analyze the aspect, which contributes to sports injuries. The correlation analysis presented in **Table 7** reveals significant insights into the relationships between biomechanical parameters and injury risk, focusing on acceleration, angular velocity, and joint stress. Acceleration shows a moderate positive correlation with injury risk (r = 0.32), but this relationship is not statistically significant (p = 0.08), indicating a weak influence. In contrast, angular velocity has a slightly stronger correlation (r = 0.37) and is on the threshold of significance (p = 0.05), suggesting its potential relevance in injury assessment. Most notably, joint stress demonstrates the strongest correlation with injury risk (r = 0.45) and a statistically significant p-value (< 0.01), highlighting its critical role in predicting injuries. Overall, while acceleration and angular velocity provide some insights, joint stress emerges as the most significant parameter, emphasizing the importance of monitoring joint stress to prevent injuries in sports and physical activities.

Table 7. Correlation analysis for biomedical parameters.

Parameter	Correlation Coefficient (r)	$\rho - \text{value}$
Acceleration	0.32	0.08
Angular Velocity	0.37	0.05
Joint Stress	0.45	< 0.01

4.3.3. Regression analysis

The purpose of the regression analysis is to forecast injury risk using biomechanical parameters as well as measure their influence on injury incidence in PE. **Table 8** illustrates the regression analysis for biomechanical parameters. Coefficients (β) assess the link among biomechanical parameters as well as injury risk, which illustrates the strength and direction of the impacts. The $t - value$ evaluates the importance of every parameter's influence on injury risk, assessing whether the association is statistically significant. The $\rho - value$ is less than 0.05 indicating significance. The biomechanical parameters outcomes in regression analysis are acceleration (Coefficient = 0.18, standard error = 0.09, $t -$ value = 2.00, $\rho -$ value = 0.046), angular velocity (Coefficient = 0.32, standard error = 0.11, $t -$ value = 2.91, $\rho -$ value = 0.004), and joint stress (Coefficient = 0.45, standard error = 0.10, $t -$ value = 4.50, $\rho -$ value $\leq$ 0.01). It concludes that biomechanical characteristics have a significant influence on injury risk, especially joint stress and angular velocity, which represent crucial predictors of injury incidence.

Table 8. Regression analysis for biomedical parameters.

Parameter	Coefficient (β)	Standard Error	$t - \text{value}$	$\rho - \text{value}$
Acceleration	0.18	0.09	2.00	0.046
Angular Velocity	0.32	0.11	2.91	0.004
Joint Stress	0.45	0.10	4.50	< 0.01

4.4. Pre- and post-rehabilitation assessment

Participants' physical performance as well as injury-related symptoms has been examined pre- and post-implementation of personalized rehabilitation program assessment. ROM and pain level (as assessed by the Visual Analog Scale (VAS)) are the metrics. It contains improvement in ROM and pain level reduction.

4.4.1. Improvement in range of motion (ROM)

The purpose is to illustrate ROM improvements for particular joints to measure the efficacy of personalized rehabilitation tactics. **Table 9** represents the ROM improvements. The wrist, ankle, knee, elbow, and torso are the included joint/body parts. Pre-rehabilitation ROM represents the average ROM in degrees for every joint or body component before beginning the rehabilitation program. It acts as a baseline assessment. Post-rehabilitation ROM displays the average ROM in degrees after finishing the personalized rehabilitation program. It indicates any improvements achieved as a result of the intervention. Improvement denotes the difference that exists between the post-and pre-rehabilitation ROM. This shows the increase in flexibility and movement that resulted from the rehabilitation program. The outcomes of Pre-Rehabilitation ROM are wrist (70°), ankle (90°), knee (130°), elbow (110°), torso flexion (50°) and torso rotation (45°). The outcomes of post-Rehabilitation ROM are wrist (85°), ankle (105°), knee (145°), elbow (125°), torso flexion (65°), and torso rotation (60°). The outcomes of improvement are 15 for all joint/body parts. It shows the significant ROM improvement in the joints which demonstrates the efficacy of personalized rehabilitation programs for increasing mobility.

Table 9. Improvement in ROM.

Joint/Body Part	**Pre − Rehabilitation ROM** (°)	**Post − Rehabilitation ROM** (°)	**Improvement** (°)
Wrist	70	85	15
Ankle	90	105	15
Knee	130	145	15
Elbow	110	125	15
Torso (Flexion)	50	65	15
Torso (Rotation)	45	60	15

4.4.2. Pain level reduction

The purpose is to assess the efficacy of personalized rehabilitation programs in lowering pain levels after the injury. **Figure 5** displays the pain level reduction. Pain levels have been assessed before and after rehabilitation utilizing the VAS. Participants assessed their pain on a scale ranging from 0 such as no pain to 10 such as the worst possible pain. Sudden onset and short-term injuries are acute injuries. Long-term and persistent injuries are chronic injuries. Pain reduction estimates the difference among pre- and post-rehabilitation pain levels, which demonstrates the average reduction in pain. The Pre-Rehabilitation pain level in acute injuries is 6.8 and chronic injuries are 7.4. The attained post-rehabilitation pain level in acute injuries is 3.2 and in chronic injuries is 4.0. The achieved pain reduction is 3.6 in acute and 3.4 in chronic injuries. It concludes that personalized rehabilitation programs substantially decreased the pain levels for acute injuries and chronic injuries, hence improving the rehabilitation outcomes.

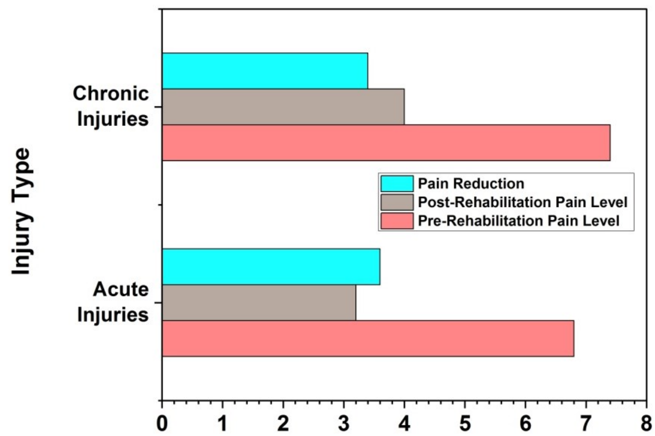

Figure 5. Graphical representation of reduction in pain levels.

5. Conclusion

Research mainly concentrated on developing injury prevention and rehabilitation strategies for PE teaching based on biomechanical characteristics. This research uses a mixed-methods approach. To begin with, student participant data have been collected. After that, the research utilized a DL approach like RCNN and statistical analysis. Finally, this study assessed the results using the identified injury detection performance utilizing the RCNN, survey outcomes, statistical analysis outcomes, and assessment of pre- and post-rehabilitation. The RCNN outcomes in performance measures are accuracy (92%), precision (89%), recall (90%), and f1-score (89.5%). Based on the results, RCNN provides better findings. The study found that individualized injury prevention and rehabilitation techniques based on biomechanical data along with RCNN significantly enhanced injury detection accuracy as well as rehabilitation efficiency in PE. Small sample sizes could be the limitation. Future work will increase the sample size and investigate the other factor variables.

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

Ethical approval: Not applicable.

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

References

1. Karasievych S, Maksymchuk B, Kuzmenko V, et al. Training Future Physical Education Teachers for Physical and Sports Activities: Neuropedagogical Approach. BRAIN Broad Research in Artificial Intelligence and Neuroscience. 2021; 12(4): 543-564. doi: 10.18662/brain/12.4/264
2. Moreno-Murcia JA, Barrachina-Peris J, Ballester Campillo M, et al. Proposal for Modeling Motivational Strategies for Autonomy Support in Physical Education. International Journal of Environmental Research and Public Health. 2021; 18(14): 7717. doi: 10.3390/ijerph18147717
3. Woods CT, McKeown I, O'Sullivan M, et al. Theory to Practice: Performance Preparation Models in Contemporary High-Level Sport Guided by an Ecological Dynamics Framework. Sports Medicine-Open. 2020; 6(1). doi: 10.1186/s40798-020-00268-5
4. Read PJ, Oliver JL, Lloyd RS. Seven Pillars of Prevention: Effective Strategies for Strength and Conditioning Coaches to Reduce Injury Risk and Improve Performance in Young Athletes. Strength & Conditioning Journal. 2020; 42(6): 120-128. doi: 10.1519/ssc.0000000000000588
5. Jacob A. Injury Prevention and Rehabilitation in Sports. International Journal of Sports, Yoga, and Physical Activity. 2023; 2(1): 3005-5083.
6. Blake M, Solberg VSH. Designing elite football programmes that produce quality athletes and future ready adults: incorporating social emotional learning and career development. Soccer & Society. 2023; 24(6): 896-911. doi: 10.1080/14660970.2022.2149505
7. Hawsawi RH, Almutairi MA, Alghamdi AJ, et al. Physical Therapy's Effectiveness in Treating Typical Sports Injuries. Journal of Namibian Studies: History Politics Culture. 2022; 32: 1150-1160. doi: 10.59670/teh5sa08

8. Piussi R, Krupic F, Senorski C, et al. Psychological impairments after ACL injury – Do we know what we are addressing? Experiences from sports physical therapists. Scandinavian Journal of Medicine & Science in Sports. 2021; 31(7): 1508-1517. doi: 10.1111/sms.13959
9. McDevitt S, Hernandez H, Hicks J, et al. Wearables for Biomechanical Performance Optimization and Risk Assessment in Industrial and Sports Applications. Bioengineering. 2022; 9(1): 33. doi: 10.3390/bioengineering9010033
10. Kolodziej M, Willwacher S, Nolte K, et al. Biomechanical Risk Factors of Injury-Related Single-Leg Movements in Male Elite Youth Soccer Players. Biomechanics. 2022; 2(2): 281-300. doi: 10.3390/biomechanics2020022
11. Towlson C, Salter J, Ade JD, et al. Maturity-associated considerations for training load, injury risk, and physical performance in youth soccer: One size does not fit all. Journal of sport and health science. 2021; 10(4): 403-412. doi: https://doi.org/10.1016/j.jshs.2020.09.003
12. Tee JC, McLaren SJ, Jones B. Sports injury prevention is complex: we need to invest in better processes, not singular solutions. Sports medicine. 2020; 50(4): 689-702. doi: https://doi.org/10.1007/s40279-019-01232-4
13. Li J. Analysis of the Causes and Rehabilitation of Ankle Injuries in Basketball Players by Sports Rehabilitation in the Context of Sports-Medicine Integration. Journal of Human Movement Science. 2024; 5(1): 104-112. doi: 10.23977/jhms.2024.050115
14. Cools AM, Maenhout AG, Vanderstukken F, et al. The challenge of the sporting shoulder: From injury prevention through sport-specific rehabilitation toward return to play. Annals of Physical and Rehabilitation Medicine. 2021; 64(4): 101384. doi: 10.1016/j.rehab.2020.03.009
15. O'Brien J, Santner E, Kröll J. Moving Beyond One-Size-Fits-All Approaches to Injury Prevention: Evaluating How Tailored Injury Prevention Programs Are Developed and Implemented in Academy Soccer. Journal of Orthopaedic & Sports Physical Therapy. 2021; 51(9): 432-439. doi: 10.2519/jospt.2021.10513
16. Liu S. Injury Prevention and Talent Retention: A Coach's Role in Sustaining Athletic Potential in Young Athletes. Studies in Sports Science and Physical Education. 2024; 2(1): 24-31. doi: 10.56397/ssspe.2024.03.03
17. Kozin S, Kozina Z, Korobeinik V, et al. Neuro-muscular training for injury prevention of students-rock climbers studying in the specialty" Physical Education and Sports": a randomized study. Journal of Physical Education and Sport. 2021; 21: 1251-1259. doi: 10.7752/jpes.2021.s2159
18. Wei W, Yalong L. Study on treatment and rehabilitation training of ligament injury of javelin throwers based on sports biomechanics. Measurement. 2021; 171: 108757. doi: 10.1016/j.measurement.2020.108757
19. Lu J. Analysis and prevention and treatment of ankle joint injury factors in basketball players based on data mining. Molecular & Cellular Biomechanics. 2024; 21: 157. doi: 10.62617/mcb.v21.157
20. Vincent HK, Brownstein M, Vincent KR. Injury Prevention, Safe Training Techniques, Rehabilitation, and Return to Sport in Trail Runners. Arthroscopy, Sports Medicine, and Rehabilitation. 2022; 4(1): e151-e162. doi: 10.1016/j.asmr.2021.09.032
21. Zhihong Y. Integrating Technology and Personalized Approaches in Sports Rehabilitation: Enhancing Performance and Preventing Sports Injuries. International Journal of Scientific and Management Research. 2023; 06(07): 16-29. doi: 10.37502/ijsmr.2023.6702
22. de Freitas FC, Fujisawa DS, Macedo CDSG. Injury prevention in elite soccer: perceptions and strategies of Brazilian soccer teams. Journal of Physical Education and Sport. 2020; 20(5): 2468-2477. doi: 10.7752/jpes.2020.05338
23. Guan D, Wang Z. Multi-objective optimization model-based training program development for athletes in college physical education. Applied Mathematics and Nonlinear Sciences. 2023; 9(1). doi: 10.2478/amns.2023.2.00338
24. Li X, Tan WH, Li Z, et al. Adaptive fitness enhancement model: Improving exercise feedback and outcomes through tailored independent physical education plan. Education and Information Technologies. Published online March 19, 2024. doi: 10.1007/s10639-024-12616-z
25. Yuan Y. Exploration of Teaching and Training Methods for Track and Field Sports in School Physical Education. Journal of Human Movement Science. 2024; 5(2): 9-15. doi: 10.23977/jhms.2024.050202
26. Mishra N, Habal BGM, Garcia PS, et al. Harnessing an AI-Driven Analytics Model to Optimize Training and Treatment in Physical Education for Sports Injury Prevention. Proceedings of the 2024 8th International Conference on Education and Multimedia Technology. 2024; 7: 309-315. doi: 10.1145/3678726.3678740
27. Zhai S. Innovative Practice of Online Teaching Model for College Physical Education Courses Empowered by Information Technology Education. In: Proceeding of the 2024 5th International Conference on Education, Knowledge and Information Management (ICEKIM 2024). doi: 10.2991/978-94-6463-502-7_123