Research on the Optimization Path of Specialized Physical Training for Football Players Empowered by Big Data

Zhiqi Zhang
College of Physical Education, Henan University of Science and Technology, Luoyang 471000, Henan, China
Corresponding author: Zhiqi Zhang (e-mail: interzzqds@163.com)

ABSTRACT In the context of the deep integration of digital technology and competitive sports, big data technology provides core support for the scientific, precise, and personalized transformation of specialized physical training for football players. Football specific physical fitness, as the foundation of players' competitive performance, covers key dimensions such as specialized endurance, explosive power, agility and coordination, core strength, and confrontation ability. Its training quality directly determines the running efficiency, confrontation intensity, attack defense transition speed, and injury prevention and control effect in the game. Traditional physical training relies on coach experience, qualitative evaluation, and standardized plans, which have prominent problems such as insufficient targeting, extensive load control, lagging injury warning, and difficulty in quantifying training effects. The sensing and load-management workflow can be implemented through wearable motion-monitoring devices used in football training.

INDEX TERMS football physical training,big data,wearable sensing,injury warning,motion sensing

I. INTRODUCTION

A. RESEARCH BACKGROUND AND SIGNIFICANCE

WITH the deepening of the digital transformation of global competitive sports, new generation information technologies such as big data, the Internet of Things, artificial intelligence, and wearable devices are being integrated into the entire process of football training, competition, and management at an unprecedented depth, becoming the core driving force for promoting the scientific and intelligent development of football. As the world's largest sport, the improvement of football's competitive level highly relies on the support of athletes' specialized physical fitness - specialized physical fitness is the foundation for players to complete technical movements, execute tactical intentions, cope with high-intensity confrontations, and maintain the efficiency of the entire game. It is also a key factor that determines the speed of team offensive and defensive transitions, game control ability, and final results[1]. The pace of modern football matches is constantly accelerating, the intensity of confrontation continues to increase, and the frequency of offensive and defensive transitions is becoming more frequent. This places higher demands on the comprehensiveness, pertinence, and practicality of athletes' specialized physical fitness. Traditional physical training models are no longer suitable for the development needs of modern football[2].

B. RESEARCH SIGNIFICANCE

Theoretical significance

Improve the theoretical framework of sports big data application. Focusing on the core scenario of football specific physical training in competitive sports, a complete theoretical framework of big data empowerment training is constructed, which includes "data collection data governance intelligent analysis scheme generation dynamic regulation effect evaluation"[3]. This enriches the application theory of sports big data in the field of specialized training and provides theoretical references and paradigms for the application of big data training in other competitive projects[4].

Promote the theoretical transformation of competitive sports training[5]. This article explores the transformation path from "experience driven" to "data-driven" training mode, explains the core connotation, value logic, and practical methods of data-driven training, promotes the transformation of competitive sports training theory from qualitative research to quantitative research, and from experience summary to scientific analysis, and enriches the theoretical connotation of scientific training in competitive sports[6].

Practical significance

Improve the level of football competition and the quality of youth training in our country. Big data empowerment of specialized physical training can accurately tap into players' physical potential, fill in their weaknesses, strengthen their advantages, enhance their specialized physical fitness and practical performance, and provide functional support for team tactical execution and game performance improve-

ment; At the same time, providing scientific selection and precise training data basis for the youth training system, promoting the transformation of China's football youth training from "experience selection" to "data selection", and consolidating the foundation of football talent cultivation[7].

Provide practical reference for the construction of smart football. This article explores the practical application mode of big data technology in football specific physical training, providing practical reference for the construction of smart football platforms, data systems, and technical standards in China, and helping to promote the digital and intelligent transformation and development of football in China[8].

C. RESEARCH METHODS

Case analysis method: Select top international clubs such as Bayern Munich, Manchester City, Barcelona, as well as professional clubs in China that have piloted the application of big data technology as cases, deeply analyze their big data physical training system, technology application mode, optimization path, and practical effectiveness, summarize advanced experience and practical inspiration, and provide case support for this study[9]. To provide longitudinal validation, this study specifically examines performance metrics and injury data from a Chinese professional club over two consecutive competitive seasons: one prior to the implementation of the big data system and one following its full integration.

D. RESEARCH INNOVATION POINTS

Firstly, innovative research perspectives. Based on a new perspective of deep integration of big data and football specific physical training, breaking through the limitations of traditional physical training research that is "experience driven", a "data-driven" research framework for specialized physical training is constructed to achieve the organic integration of digital technology and competitive sports training, forming a new research perspective.

Secondly, research system innovation. Build a comprehensive and systematic big data empowerment system for specialized physical training optimization, which includes data collection, data governance, intelligent analysis, solution generation, load regulation, injury warning, and effectiveness evaluation. This will break through the fragmented and one-sided shortcomings of existing research and form a comprehensive and closed-loop research framework.

Thirdly, innovative path design. Based on the physiological characteristics of Chinese players, the actual development of football, and the specific physical fitness needs, an optimization path of "multi-source data fusion+intelligent model analysis+personalized solutions+dynamic regulation+closed-loop feedback" is proposed, covering four major support systems: technology, talent, system, and ethics. The path design combines theoretical, practical, and localized adaptability.

Fourth, practice and apply innovation. Focusing on the specialized physical fitness differentiation needs of players in different positions of football, designing localized and personalized training optimization plans, constructing a implementable and operable big data physical fitness training implementation process, providing direct practical guidance for professional clubs and youth training institutions, and promoting the transformation of research results into practice.

II. CORE CONCEPTS AND THEORETICAL FOUNDATIONS

Big data refers to a collection of data that cannot be captured, managed, and processed using conventional software tools within a certain time frame. It is a massive data resource characterized by massive scale, high-speed generation, diverse types, low value density, and high authenticity[10]. In the field of football specific physical training, big data covers players' physiological data (heart rate, blood oxygen, blood lactate, muscle electrical signals, etc.), kinematic data (running distance, speed, acceleration, number of changes, jumping height, etc.), training load data (subjective fatigue, training intensity, training volume, etc.), game performance data, injury history data, environmental data and other multi-source, multi-dimensional, massive data. Through big data technology, data collection, storage, management, analysis and application are achieved to provide data support for training decisions[11].

III. THE CORE CONNOTATION AND TRADITIONAL MODE DILEMMA OF SPECIALIZED PHYSICAL TRAINING FOR FOOTBALL PLAYERS

A. CORE COMPONENTS AND POSITIONAL REQUIREMENTS OF SPECIALIZED PHYSICAL FITNESS FOR FOOTBALL PLAYERS

Core components of specialized physical fitness

Core strength. Core strength is the core that connects the upper and lower limbs, transmits strength, maintains body posture, and resists stability, covering core stability, core strength endurance, and core explosive power[12]. The core indicators include core muscle strength values, trunk stability test results, and body balance ability during confrontation, which directly affect the efficiency of players' technical movements, body control during confrontation, and the effectiveness of injury prevention and control[13].

Physicality in duels. Physicality in duels refers to the comprehensive ability of players to complete technical movements, maintain body balance, and compete for possession through physical contact. This encompasses the intensity of physical engagement, power output during contests, and the stability of technical execution under pressure. The core indicators include the success rate of duels and the fatigue index associated with high-intensity physical contact[14]. The core indicators include the number of confrontations, the success rate of confrontations, the rate of technical errors during confrontations, and the fatigue index of confrontations, which are key physical elements in modern football high-intensity confrontation scenarios[15].

Characteristics of specialized physical fitness needs of players in different positions

In the modern football tactical system, there are significant differences in the functional division, activity scope, and game tasks of players in different positions, as shown in Table 1. Their specific physical fitness needs exhibit obvious positional characteristics:

TABLE 1. Composition and Demand Characteristics of Football Players' Special Physical Fitness

Physical Fitness Dimension	Core Quality Requirements	Main Test Indicators	Differentiated Demand by Position
Special Endurance	High-intensity intermittent running and whole-game endurance	Total running distance, high-speed running distance, heart rate recovery	Midfielders > Full-backs > Forwards > Defenders > Goalkeepers
Explosive Power	Starting acceleration, sprint and jumping ability	10m sprint, vertical jump, peak acceleration	Forwards > Wingers > Central Defenders > Goalkeepers
Agility and Coordination	Quick direction change, reaction and balance	Direction change speed, reaction time, balance index	Wingers > Forwards > Full-backs > Midfielders
Core Strength	Trunk stability and anti-collision ability	Core muscle endurance, torso stability value	Central Defenders > Midfielders > Full-backs

Frontline: The core requirements are explosive power, agility and coordination, and specialized endurance. Frequent starting sprints, changing directions, competing for headers, and high-intensity confrontations are required, with extremely high demands for 10/30 meter sprinting speed, changing direction speed, jumping height, and short-term high-intensity endurance[16]. At the same time, specialized endurance for continuous running throughout the entire field is required[17].

Edge/Vanguard: The core requirements are specialized endurance, explosive power, and agile coordination[18]. It requires a wide range of back and forth running, high-speed breakthroughs, rapid directional changes, and offensive and defensive transitions throughout the entire field. It has outstanding requirements for total running distance, high-speed running distance, sprint frequency, and directional ability, and is one of the positions with the highest running intensity throughout the field[19-20].

Midfielder: The core requirements are specialized endurance, core strength, and confrontational ability. As the hub of the team's offensive and defensive transition, it requires continuous running, organizing attacks, intercepting defenses, and high-intensity confrontations. It has extremely high requirements for total running distance, high-intensity running duration, core strength, and endurance in confrontation, making it the position with the highest physical energy consumption throughout the game.

Central defender: The core requirements are explosive power, core strength, and confrontational ability. It is necessary to complete the competition for header, defensive interception, physical confrontation, and fast pursuit, with outstanding requirements for jumping height, opposing strength, core stability, and short distance sprint speed. The specific endurance requirements are relatively lower than those of middle and front court players, but the intensity of confrontation is extremely high.

Full back: The core requirements are specialized endurance, explosive power, and agile coordination. It is necessary to complete back and forth sprinting on the flank, transition between offense and defense, defensive interception, and assist insertion. The requirements for total running distance, high-speed running distance, turning speed, and starting speed are extremely high, combining the running intensity of a winger with the confrontational needs of a defender.

Goalkeeper: The core requirements are explosive power, agility and coordination, and core strength. It is necessary to complete rapid response, firefighting, jumping, movement, and confrontation, with outstanding requirements for reaction speed, vertical jumping height, agility, and core stability. The demand for specialized endurance is relatively low, but the requirements for instantaneous explosive power and sensitive coordination ability are extremely high.

Mode and Process of Traditional Football Specialized Physical Training

B. EVOLUTION FROM CONVENTIONAL SCIENTIFIC TRAINING

Traditional football specialized physical training is based on the core model of "coach experience led, unified plan implementation, and qualitative evaluation feedback", which is manifested in three major characteristics: While modern football training has long incorporated scientific principles such as periodization and basic physiological monitoring, the conventional mode primarily relies on discrete, periodic laboratory tests and qualitative expertise. The enhancement provided by Big Data technology does not replace the scientific foundation of modern coaching but rather addresses the limitations of low-frequency data. Where traditional methods might use periodic VO2 max tests or post-session RPE scales, the data-driven approach integrates high-frequency, real-time multi-source variables, moving from static scientific planning to dynamic, high-resolution optimization of the established training foundations.

The second is a unified training plan. Adopting a "one size fits all" training model, ignoring individual differences, position requirements, and physical weaknesses of players, the entire team executes the same training content, intensity, and quantity, making it difficult to adapt to the personalized needs of different players, resulting in uneven training effects.

The third is qualitative evaluation feedback. The evaluation of training effectiveness and players' physical fitness relies on the subjective observation of coaches, players' self perception, and simple physical fitness tests (such as 1000 meter running and standing long jump), lacking quantitative indicators and accurate evaluation, with feedback lagging

and vague, making it difficult to support training optimization.

C. TRADITIONAL TRAINING PROCESS

The traditional specialized physical training process is divided into four major stages, forming a simple closed loop of "planning implementation evaluation adjustment":

Step 1: Develop a training plan. The coach formulates a unified specialized physical training plan based on competition tasks, training cycles, and experience judgment, determining the training content (such as interval running, strength training, agility training), training volume, and training intensity.

Step 2: Training implementation. The whole team follows a unified training plan, with coaches providing onsite guidance, correcting movements, and controlling the training pace. However, it is difficult to accurately monitor the training load and physical condition of each player.

Step 3: Effect evaluation. After the training, the training effect is evaluated through simple physical fitness tests, subjective observations by coaches, and self feedback from players, but there is a lack of accurate quantitative evaluation of players' physical fitness status, fatigue accumulation, and training load.

Section 4: Plan Adjustment, Based on the evaluation results and experience judgment, the coach made rough adjustments to the subsequent training plan, but the direction and magnitude of the adjustments lacked data support, and the targeting and accuracy were insufficient, as shown in Table 2 below.

TABLE 2. Defect Comparison Between Traditional Training Mode and Big Data Training Mode

Comparison Dimension	Traditional Physical Training Mode	Big Data Enabled Training Mode	Main Defects of Traditional Mode
Training Decision	Experience-driven and subjective judgment	Data-driven and quantitative analysis	Lack of objective basis and scientificity
Training Plan	Unified and one-size-fits-all scheme	Personalized and position-oriented scheme	Ignoring individual physical differences
Load Management	Empirical control and rough evaluation	Real-time monitoring and dynamic adjustment	Excessive training or insufficient load
Injury Prevention	Post-event treatment and passive intervention	Early warning and active prevention	Serious lag of risk identification

D. LONGITUDINAL VALIDATION OF DATA-DRIVEN OPTIMIZATION

To verify the optimization effectiveness of big data empowerment, a longitudinal comparison was conducted on a domestic professional football team during the 2024 (pre-implementation) and 2025 (post-implementation) competitive seasons. As shown in Table 3:

TABLE 3. Comparative Analysis of Seasonal Performance and Injury Metrics

Metric Category	2024 Season (Experience-Driven)	2025 Season (Data-Driven)	Improvement/ Change
Non-contact Injury Rate	1.42 per 1000h training	0.89 per 1000h training	-37.30%
High-Intensity Running Distance	842m ± 115m	956m ± 98m	13.50%
Post-Game Recovery Time (HRV-based)	48.2 hours	39.5 hours	-18.10%
Squad Availability (Average)	82%	91%	11%

The data indicates that the implementation of real-time load monitoring and early warning systems significantly reduced the incidence of non-contact soft tissue injuries. Furthermore, the personalized specialized endurance modules led to a measurable increase in high-intensity running output during the final 15 minutes of matches, providing empirical evidence for the optimization path proposed in this research.

IV. THE APPLICATION PRINCIPLE AND CORE VALUE OF BIG DATA EMPOWERING FOOTBALL SPECIFIC PHYSICAL TRAINING

A. TECHNICAL FRAMEWORK FOR EMPOWERING FOOTBALL SPECIFIC PHYSICAL TRAINING WITH BIG DATA

The technical framework for empowering specialized physical training with big data is divided into four levels, with each level working together to form a complete technical system:

Perception layer: composed of hardware devices such as wearable devices, GPS trackers, physiological monitors, video cameras, training management terminals, etc., responsible for real-time collection and transmission of multi-source data, and is the foundation of data sources.

Data layer: composed of a data storage platform and a data governance platform, responsible for the storage, cleaning, integration, standardization, and management of data, building a player specific physical fitness database, and ensuring the security, integrity, and availability of data.

Analysis layer: composed of a big data analysis platform, machine learning models, and artificial intelligence algorithms, responsible for deep data analysis, feature mining, model training, and intelligent decision-making. It is the core of technology empowerment.

Application layer: composed of physical fitness assessment system, training plan generation system, load monitoring system, injury warning system, and effectiveness evaluation system, responsible for converting analysis results into visual interfaces, training instructions, and warning information, providing direct application services for coaches and players.

B. THE CORE VALUE OF BIG DATA EMPOWERING FOOTBALL SPECIFIC PHYSICAL TRAINING

Big data achieves panoramic and accurate monitoring of players' specialized physical fitness status through real-time collection and quantitative analysis of multi-source data, filling the blind spots in coach experience observation. It can accurately quantify the level of a player's specialized endurance, explosive power, sensitive coordination, core strength, and combat ability, monitor indicators such as heart rate, blood lactate, running data, fatigue index in real-time during training, objectively present the player's physical advantages, weaknesses, and real-time status, and provide accurate basis for training decisions.

V. OPTIMIZATION PATH CONSTRUCTION OF FOOTBALL SPECIFIC PHYSICAL TRAINING EMPOWERED BY BIG DATA

A. BUILDING A MULTI-SOURCE FUSION SPECIALIZED PHYSICAL FITNESS DATA COLLECTION SYSTEM

Clarify the dimensions and core indicators of data collection

Based on the core components of football specific physical fitness, five categories of data collection dimensions and core indicators are determined to achieve comprehensive and targeted data collection:

Kinematic data dimension: The core indicators include total running distance, high-speed running distance (>19.8km/h), sprint distance (>25.2km/h), 10/30 meter sprint time, number of changes in direction, change in direction speed, jump height, acceleration/deceleration, running trajectory, and number of confrontations, reflecting the player's specialized sports performance.

Dimension of training load data: The core indicators include training volume, training intensity, training density, load index (SRPE), cumulative fatigue value, and recovery time, reflecting the relationship between training load and player tolerance.

Dimension of competition performance data: The core indicators include running data, success rate of confrontation, completion rate of skills, participation in offense and defense, and execution effect of position and function, reflecting the practical transformation effect of specialized physical fitness.

Injury and recovery data dimensions: Core indicators include historical injury records, injury types, injury locations, recovery time, recovery training data, sleep quality, reflecting injury risk and recovery status.

Building a multimodal data acquisition hardware system

Integrate wearable devices, video analysis, physiological monitoring, and terminal management devices to build a multimodal, imperceptible data acquisition hardware system:

Wearable monitoring devices: Equip players with 10Hz GPS vests, heart rate bands, muscle electrical sensors, and acceleration sensors to achieve real-time collection and wireless transmission of physiological and kinematic data during training and competition, ensuring the continuity and accuracy of data collection.

Video analysis system: Install high-definition cameras and AI visual analysis systems in training and competition fields to capture players' running trajectories, motion details, confrontation scenes, and technical completion status without perception, supplementing motion and scene data that wearable devices cannot collect.

Physiological monitoring equipment: equipped with portable blood lactate detectors, oximeters, and body composition analyzers, regularly collecting in-depth physiological data to improve the physical fitness assessment dimensions of players.

Terminal management equipment: Equip coaches with tablets and mobile terminals to receive and view player data in real time, achieve on-site data monitoring and command issuance; Build a data collection and management platform to unify the management of all hardware devices and data transmission, as shown in Table 4 below.

TABLE 4. Multi-source Data Collection Index System for Football Special Physical Training

Data Category	Collection Content	Collection Equipment	Collection Frequency
Physiological Data	Heart rate, blood lactic acid, oxygen saturation	Heart rate belt, portable physiological detector	Real-time in training and competition
Kinematic Data	Sprint distance, direction change, acceleration	GPS wearable vest, motion sensor	Full-time dynamic collection
Training Load Data	Training intensity, load index, fatigue accumulation	Smart terminal and training management system	Daily after training
Competition Performance Data	Confrontation times, technical completion rate	AI video analysis system	After each match
Health Recovery Data	Sleep quality, injury history, recovery cycle	Physical examination equipment and health platform	Regular daily collection

Establish standardized data collection processes and specifications

Develop standardized processes and specifications for data collection to ensure data quality: clarify the data collection nodes before, during, and after training, collect basic physiological data before training, collect dynamic data in real-time during training, and collect recovery data after training; Standardize the operational procedures for equipment wearing, data transmission, and data labeling; Establish a data quality verification mechanism to monitor data integrity, accuracy, and effectiveness in real-time, and eliminate abnormal data; specifically, implement a 'dual-track verification' protocol where high-risk injury alerts triggered by automated sensors must be cross-referenced with the player's subjective perceived exertion (RPE) and clinical physical assessment to prevent unnecessary removal from training due to data-only 'false positives'; Clearly define the frequency and duration of data collection to ensure comprehensiveness and representativeness of data collection.

B. RESEARCH AND DEVELOPMENT OF DATA GOVERNANCE AND INTELLIGENT ANALYSIS MODEL SYSTEM

Building a specialized physical fitness data governance system

Establish a full process data governance system of "data cleaning data integration data annotation data storage": use data cleaning techniques to eliminate invalid, missing, and abnormal data, and correct data errors; Breaking down data silos through data integration technology, integrating physiological, kinematic, load, match, and injury data into a unified player specific physical fitness dataset; Standardize data labeling, clarify data types, indicator meanings, and collection scenarios; Build a distributed data storage platform to achieve secure storage, fast retrieval, and shared use of data, ensuring data availability and security.

Develop a specialized physical and intelligent evaluation model

Based on machine learning algorithms and physiological threshold modeling, develop an intelligent evaluation model. The system utilizes Random Forest (RF) algorithms to analyze raw kinematic data (acceleration/speed) against historical fatigue markers to establish personalized load thresholds. Furthermore, Long Short-Term Memory (LSTM) networks are employed to process temporal sequences of physiological data (HRV, blood lactate) to predict overtraining risks. By comparing real-time output against these pre-calculated physiological benchmarks, the system automatically generates specific training volume adjustments (e.g., $\pm 10\%$ intensity shifts) to bridge the gap between raw monitoring and practical optimization:

Specialized endurance assessment model: Integrating data such as running distance, proportion of high-speed running, heart rate, blood lactate, fatigue index, etc., a specialized endurance quantitative assessment model is constructed to accurately evaluate players' aerobic and anaerobic endurance levels and classify endurance levels.

Explosive Power Evaluation Model: By integrating data such as sprint time, jump height, acceleration, and resistance, an explosive power evaluation model is constructed to quantify the explosive power levels of players' lower limbs, core, and upper limbs.

Sensitivity Coordination Evaluation Model: Based on data such as change speed, reaction time, accuracy of action completion, and balance ability, a sensitivity coordination evaluation model is constructed to assess the dynamic sensitivity and coordination level of players.

Core Strength Assessment Model: Integrating data on core muscle group strength, trunk stability, and resistance balance ability to construct a core strength assessment model and quantify core strength levels.

Adversarial ability evaluation model: Integrating data such as the number of confrontations, success rate of confrontations, technical error rate during confrontations, and fatigue index of confrontations, a adversarial ability evaluation model is constructed to assess the actual combat level of players, as shown in Table 5.

TABLE 5. Function Modules and Implementation Objectives of Big Data Intelligent Analysis Model

Intelligent Model Type	Core Function Module	Technical Means	Implementation Goal
Special Fitness Evaluation Model	Quantitative scoring of five physical dimensions	Machine learning and data mining	Accurately identify physical advantages and weaknesses
Training Load Regulation Model	Individual load threshold setting and early warning	Dynamic data comparison and algorithm calculation	Balance training volume and physical bearing capacity
Injury Risk Early Warning Model	Risk factor identification and grade assessment	Deep learning and historical data correlation analysis combined with secondary subjective verification	Minimize the incidence of non-contact sports injuries while mitigating the risk of 'false positive' alerts
Personalized Scheme Recommendation Model	Position matching and weak item targeted training	Feature screening and intelligent matching algorithm	Realize one-person-one-strategy refined training
Training Effect Evaluation Model	Horizontal and vertical data comparison	Multi-index comprehensive scoring	Quantify training improvement and closed-loop optimization

C. DESIGN A PERSONALIZED SPECIALIZED PHYSICAL TRAINING PROGRAM GENERATION SYSTEM

Building a personalized training program intelligent recommendation system based on player digital portraits, position requirements, and training objectives: designing location-based training content modules for different position players' specific physical fitness needs (such as forwards focusing on explosive power and agility training, midfielders focusing on specific endurance and core strength training); Match targeted reinforcement training content for individual physical weaknesses of players; Intelligent recommendation of training methods, intensity, frequency, and cycle, generating personalized specialized physical training plans with "one person, one strategy".

Design specialized and scenario based training content modules around the core elements of football specific physical fitness, avoiding isolated physical training and achieving the integration of physical fitness with technology and tactics

Specialized endurance module: designed to combine high-intensity interval training with ball, small field confrontation training, and offensive and defensive transition running training, simulating the rhythm of intermittent running in games and enhancing specialized endurance.

Explosive Power Module: Design resistance sprint training, jump box training, medicinal ball burst throwing training, and adversarial take-off training, combined with football technique movements, to enhance specialized explosive power.

Sensitive Coordination Module: Design training for changing direction, responsive receiving, dynamic balance,

and tactical agility to enhance the ability to coordinate in real-world scenarios.

Core Strength Module: Design dynamic core training, resistance core training, and confrontation core stability training, combined with the characteristics of football power, to strengthen core strength and stability.

Adversarial Ability Module: Design training for physical confrontation techniques, complete training for techniques during confrontation, and high-intensity interval training to enhance practical combat abilities.

VI. BUILDING A SUPPORTING SYSTEM FOR SPECIALIZED PHYSICAL TRAINING EMPOWERED BY BIG DATA

A. TECHNICAL IMPLEMENTATION AND COST-BENEFIT FRAMEWORK

To ensure the practical feasibility across different tiers of football organizations, the technical system adopts a "modular implementation" strategy. For elite clubs, a full-spectrum integration of high-frequency sensors is recommended; however, for youth academies and non-elite clubs, a phased investment model focusing on high-impact, low-cost variables (such as sRPE and basic GPS metrics) provides a favorable cost-benefit ratio. The optimization path emphasizes that the goal is not the pursuit of exhaustive data but the maximization of "marginal training gains"—ensuring that the financial investment in professional data teams aligns with the specific performance objectives and economic scale of the organization, thereby avoiding resource wastage on low-utility data points.

B. COMPREHENSIVE TALENT CULTIVATION SYSTEM

Cultivate a "physical fitness+data" composite coach

Conduct big data technology application training for existing physical fitness coaches: training in skills such as data collection, platform operation, data analysis, and intelligent model application to enhance coaches' data literacy and technical application abilities; Train coaches to transition from "experience judgment" to "data-driven" thinking, and be able to develop training plans and implement dynamic regulation based on data.

Introduction and cultivation of professional data analysts

Introduce sports data analysts and big data technology talents, and establish a professional data team; Train composite data analysts who are proficient in both football specific physical fitness and big data analysis, responsible for data governance, model development, data analysis, and report generation; Establish a collaborative working mechanism between data analysts and fitness coaches to achieve deep integration of technology and training, as shown in Table 6.

TABLE 6. Supporting System and Guarantee Measures for Big Data Training Application

Guarantee System	Key Construction Content	Specific Implementation Measures	Expected Application Effect
Technical Support System	Smart training platform and hardware equipment upgrading	Unified data standard, equipment networking and algorithm optimization	Realize integrated data collection and analysis
Compound Talent System	Data literacy training and professional analyst introduction	Coach skill training, sports data talent team building	Break the barrier between technology and physical training
Institutional Normative System	Training management system and assessment mechanism	Formulate data application specifications and daily supervision rules	Standardize the whole process of digital training
Data Security System	Data encryption, access authority and privacy protection	Establish data classified management and confidentiality system	Ensure player personal information and sports data security
Humanistic Ethics System	Rational data application and human-centered training	Avoid excessive data dependence and respect individual physical differences	Balance digital empowerment and sports humanistic care

Enhance players' data literacy and autonomous application ability

Conduct player data literacy training to help players understand the meaning of specialized physical fitness data, the significance of monitoring indicators, and the basis for training programs; Guide players to independently view personal data reports, understand their physical condition and training effectiveness, and actively cooperate with training and recovery; Cultivate players' awareness of data application and achieve a positive interaction between players, coaches, and data systems.

C. CONSTRUCTION SYSTEM OF INSTITUTIONAL NORMS

Develop a big data physical training management system

Develop a management system for specialized physical training empowered by big data: clarify the division of responsibilities and operational processes for data collection, use, and management; Standardize the work system for the use of intelligent platforms, implementation of training plans, load regulation, and injury and disease warning; Establish a working mechanism for training effectiveness evaluation, data feedback, and program optimization to ensure the standardized operation of big data training.

Establish a training quality supervision and assessment system

Incorporate the implementation, training effectiveness, and injury prevention and control effects of big data physical training into the assessment system for coaches and teams; Develop quality supervision standards for specialized physical training, regularly inspect the execution of data collection, program implementation, load regulation, and effectiveness evaluation; Establish an assessment and incen-

tive mechanism to motivate coaches and teams to actively apply big data technology and improve training quality.

Improve the linkage system between youth training and professional teams

Synchronize the construction of a big data physical training system in the youth training system, and achieve the connection of data standards and training systems between youth training and professional teams; Establish a specialized physical fitness digital portrait for youth training players to track their physical changes during their growth process; Develop personalized physical training programs for young players, achieving seamless transition from youth training to professional team physical training, and consolidating the foundation of talent cultivation.

D. DATA SECURITY AND ETHICAL STANDARDS SYSTEM

Big data empowers training with the core goal of improving players' physical fitness and ensuring their health, adhering to sports training ethics: avoiding excessive reliance on data, neglecting players' subjective feelings and humanistic care; Based on data decision-making, make comprehensive judgments by combining players' physical feelings and psychological states. To address potential logical inconsistencies in automated warnings, the system adopts a 'Human-in-the-loop' decision-making framework. When the model identifies an injury risk, the medical and coaching staff conduct a secondary evaluation—including functional movement screening and muscle fatigue tests—to determine if the data reflects a genuine pathological risk or a 'false positive' caused by environmental noise or individual physiological variance. This prevents the management crisis of 'unnecessary benching' and ensures that data serves as a supportive tool rather than an absolute decider; Respect the wishes of players, ensure their right to know and participate in data collection and training programs, and achieve the organic unity of data-driven and humanistic care.

Develop ethical standards for big data applications, clarify the boundaries and responsibilities for the use of intelligent models; Ensure the fairness and objectivity of the analysis model, and avoid training unfairness caused by data bias; Regularly verify the accuracy of the model and promptly correct model errors; Establish a data application accountability system to hold accountable those who violate data usage and misuse models, ensuring the compliance and ethics of big data applications.

VII. RESEARCH CONCLUSION

This article is based on the background of the deep integration of big data and football specific physical training. It systematically studies the optimization path of football players' specific physical training under the empowerment of big data. Through longitudinal comparison of competitive seasons, this study confirms that the data-driven approach significantly reduces injury risk and enhances physical output compared to traditional experience-based models. It draws the following core conclusions:

Football specific physical fitness is the core foundation of a player's competitive performance, covering five dimensions: specific endurance, explosive power, agility and coordination, core strength, and confrontational ability. There are significant differences in the specific physical fitness needs of players in different positions. Traditional specialized physical training is based on experience driven and standardized programs, but it faces prominent challenges such as insufficient targeting, extensive load control, lagging injury warning, vague effectiveness evaluation, and lack of feedback mechanisms, making it difficult to adapt to the development needs of modern football.

In the future, with the continuous iteration of technologies such as big data, artificial intelligence, and the Internet of Things, as well as the deepening of digital transformation of football, big data empowering football specific physical training will develop towards intelligence, personalization, integration, and full cycle direction, presenting four major trends:

One is the upgrade of technological intelligence. The interpretable artificial intelligence, edge computing, digital twins and other technologies will be deeply applied to special physical training, and the accuracy, interpretability and real-time of the intelligent analysis model will be greatly improved, realizing the high intelligence and automation of training decisions, and further improving the training efficiency and accuracy. The second is to deepen personalized training. Based on in-depth mining of player lifecycle data, personalized training programs will be more precise and refined, achieving a transition from "position personalization" to "individual precision". Exclusive training programs will be developed for each player's genetic characteristics, physiological features, and physical weaknesses, maximizing the exploration of their physical potential. The third is the integration and expansion of multiple fields. Big data technology will be deeply integrated with sports medicine, psychology, nutrition, and rehabilitation studies to build an integrated training system of "physical training injury prevention and control nutrition supply psychological regulation rehabilitation regeneration", achieving comprehensive improvement of players' physical fitness, health, and psychology. The fourth is full cycle management coverage. Big data empowerment will cover the entire life cycle of players from youth training to career, from training to competition, from recovery to retirement, constructing a digital archive of players' specialized physical fitness throughout the entire cycle, achieving continuous tracking, dynamic optimization, and long-term management of physical training, and providing comprehensive support for the healthy development of players' professional careers.

AUTHOR CONTRIBUTIONS

Zhiqi Zhang designed, collected and analyzed the data, and drafted the manuscript. Zhiqi Zhang conducted the study,

critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Zhiqi Zhang participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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