Innovative Design and Performance Study of Badminton Storage Device Based on Human Factors Engineering

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Abstract. Frequent bending to retrieve balls during multi-ball training in badminton not only severely disrupts the overall rhythm and density of the exercise but also directly exacerbates athletes' physical fatigue. This study innovatively designs an efficient storage device based on ergonomic principles. By integrating a "roller shaft-radial rod" composite collection module with a planetary gear differential power system, the device achieves a collection success rate exceeding 95%. Combined with lightweight construction (1.8±0.2 kg) and biomechanically optimized structural design. This device effectively addresses the efficiency and health challenges of traditional ball retrieval methods, providing an innovative solution that combines high functionality with exceptional user experience in applying ergonomic principles to professional sports equipment.

Keywords: badminton storage device, ergonomics, exercise fatigue

1 Introduction

Multi-ball training serves as a primary auxiliary method to enhance badminton players 'technical and tactical proficiency. However, this specialized training commonly faces a notable "efficiency bottleneck": Athletes and coaches must expend considerable time repeatedly bending and squatting to retrieve scattered shuttlecocks. Based on preliminary on-site observations and coach interviews, during a 5-minute high-intensity multi-ball training session, non-essential ball retrieval and cleanup activities during interruptions account for up to 15%-20% of total duration. These frequent interruptions significantly reduce effective hitting practice time, decrease training density, disrupt athletes' training rhythm and focus, and ultimately diminish training effectiveness. Additionally, hundreds to thousands of repeated bending motions substantially increase pressure on the lumbar spine and knee joints, making athletes prone to training fatigue.

Drawing on human factors engineering principles, this innovative multi-ball training system for badminton is designed to enable rapid, effortless, and efficient recovery and delivery. Transforming traditional storage devices from passive containers into active

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efficiency enhancers, it utilizes an innovative rapid collection mechanism and ergonomic delivery system. By minimizing training interruptions and reducing unnecessary physical exertion, the system ensures uninterrupted multi-ball drills, ultimately boosting training effectiveness. More than just a practical tool for athletes and coaches to enhance training intensity and combat fatigue, this design methodology provides valuable insights for advancing sports equipment innovation and human-centered design. With proven applicability, it demonstrates significant potential for widespread adoption in professional training environments.

2 Research Status

2.1 Research Status of Badminton Ball Picking Equipment

Peter et.al.[1] developed a prototype robot for collecting table tennis balls, based on research into the necessary technology and robots currently in use, enabling practice in a venue suitable for hobby level support.

Wang[2] developed a path planning method for intelligent tennis ball pickers using twin network target tracking algorithm. The results showed the method achieved a path length of 42.07 meters and a processing time of 56.12 seconds, significantly outperforming other approaches. This demonstrates that the proposed method provides robots with precise target positioning data, optimizes trajectory planning, and enhances tennis ball retrieval efficiency.

Huang et.al.[3] used the improved indoor positioning algorithm based on weighted factor and virtual reference label to study the tennis ball picking robot, and found that the accuracy rate and average accuracy rate of the algorithm were 0.983 and 94.6% respectively, which is conducive to improving the accuracy of the robot image target positioning.

Huang et.al[4] relies on the ducted fan power as the main ball-picking mechanism, and conducts research and invention on the intelligent ball-picking robot, which integrates a variety of functions, including remote control, Bluetooth, track following, distance sensing and obstacle avoidance, ducted fan power supply, solar energy, visual recognition, etc.

Huang et.al.[5] uses visual recognition, SLAM mapping and rotating picking mechanical structure to design the intelligent tennis ball picking robot. The designed intelligent tennis ball picking robot can effectively identify, pick up and store the tennis ball, and has good dust removal effect.

Shen et.al.[6] uses Canny edge detection and Hough circle detection to study the target positioning recognition of the automatic moving ball-picking robot, and finds that the ball-picking robot under the design method in this paper can effectively identify tennis balls and has high positioning accuracy.

Tan[7] investigated the vision system of the table tennis ball recovery machine by adopting high-resolution camera shooting combined with Canny edge detection and Hough circle detection methods, achieving accurate recognition, classification, and position localization of table tennis balls.

Huang et al.[8] adopted an improved indoor positioning algorithm with virtual reference tags to investigate the positioning accuracy of the automatic tennis ball-picking robot. It was found that the precision rate and average precision rate of this algorithm are superior to those of the comparison algorithms, presenting good practical value.

Sun Zhengyang et al.[9] developed a comprehensive design framework with detailed configurations for key components, incorporating a three-wheeled omnidirectional chassis and robotic arms equipped with sensors. Their research addressed automated ball collection, sorting, and organization for table tennis, tennis, and badminton balls. The autonomous ball-picking system demonstrated capabilities including mixed-ball handling, injury-free processing, obstacle-avoiding navigation, and seamless integration with sports venues. Featuring a compact structure, agile steering, high efficiency, cost-effectiveness, and reliability, the system shows significant commercial potential and broad applicability across various sports facilities.

Shi et al.[10] adopted the method of image acquisition, contour feature recognition and localization, and a spring-loaded ball-picking device to investigate the control system of the intelligent table tennis ball-picking cart, mainly proposing a corresponding design scheme that can realize the recognition, tracking and automatic ball-picking of table tennis balls.

In the field of badminton ball retrieval devices, there are significant differences in research and development between domestic and international efforts. Domestic research primarily focuses on practical development of simplified devices, such as foldable ball retrieval nets and telescopic ball retrieval machines—low-cost equipment that meets basic functional requirements. However, these simple, low-cost devices suffer from limited functionality, manual operation dependence, and insufficient ergonomic optimization. Some Chinese universities have attempted to achieve semi-automated ball retrieval through mechanical design, but limitations like bulky size and poor adaptability to venue conditions have constrained progress. Compared to domestic research, international studies in this field emphasize technological innovation and intelligent devices. Examples include Japan's wheeled visual recognition ball retrieval robots and Europe/America's pneumatic ball suction devices[11]. However, these advanced systems remain costly and require highly specialized venue conditions.

Through technical analysis of current badminton ball retrieval devices, three core shortcomings have been identified. First, the integration of functions remains inadequate, with most devices only providing basic ball collection capabilities without integrated multifunctional designs. Second, ergonomic adaptability is insufficient, as many devices fail to consider user postures, leading to physical fatigue during prolonged use. Third, the level of intelligence is relatively low, with few integrating sensor technology or automation systems. To address these deficiencies, this design adopts human factors engineering as its theoretical foundation, establishing a three-in-one collaborative optimization model that integrates human-machine-environment synergy. By incorporating adjustable structures to accommodate different user body types and operational habits, along with lightweight construction and low-energy consumption sensor technology, the system achieves semi-automated operation. This design effectively bridges the technical gap between human-centric design and functional enhancement, serving as a model for upgrading sports equipment in the direction of intelligence. It also efficiently promotes the development of cost-effective, high-adaptability badminton training auxiliary devices.

2.2 Application of Ergonomics in Sports Equipment

Research on the application of ergonomics in sports equipment demonstrates significant domestic and international variations. Wu Yongqiang investigated ergonomic considerations in fitness equipment design, systematically summarizing ergonomic design methodologies. These include universal design principles, software-focused design approaches, human-centered standardization processes, and aesthetic styling techniques, providing practical references for practical design applications.

Domestic research on human factors engineering primarily focuses on sports protective gear and fitness equipment, while systematic studies on badminton training aids remain scarce. Unlike domestic research, international studies emphasize intelligent user experience and data-driven processing. American researchers utilize embedded sensors for real-time posture monitoring, the EU employs virtual simulation technology to optimize human-machine compatibility, and Japan has achieved significant breakthroughs in integrating lightweight materials with wearable devices. Although these studies didn't directly equip badminton training aids, they provide crucial theoretical references and technical value for this design.

3 Relevant Theoretical Basis and User Needs Analysis

3.1 Core Theories and Applications of Ergonomics

This design framework for the badminton storage device is guided by three core ergonomics principles. The "Size Adaptability" design utilizes anthropometric data from the 5th to 95th percentiles to determine adjustable handle dimensions and grip diameters that ensure ergonomic comfort for users of various body types. From a biomechanical perspective, the system optimizes operational efficiency through theoretical knowledge application. Dynamic simulation analysis demonstrates that the foot-assisted mechanism reduces lumbar spine load by 32.5%, while maintaining a comfortable weight of 1.8(±0.2)kg that aligns with natural muscle force application patterns.

In the design of a badminton storage device, the goal is to reduce operational costs and enhance user engagement, achieving a balance between cognitive simplicity and emotional appeal. From a cognitive perspective, the intuitive interaction design employs red, blue, and green color coding to distinguish functional modules, enabling quick storage. Emotionally, the design incorporates dynamic curve shapes paired with high-contrast colors, along with real-time voice counting functionality that significantly boosts user satisfaction. This approach reduces operational errors by 40.8 percentage points while substantially increasing usage frequency.

3.2 Target User In-depth Research and Demand Mining

User Group Definition and Feature Analysis.

In order to deeply understand the real needs of users in multi-ball badminton training, a questionnaire was prepared, and different groups were randomly selected to fill in the questionnaire. Finally, the results were exported and sorted. The specific data are shown in Table 1.

Table 1. User in-depth research analysis

target groups	sample capacity	Core needs	Key pain points	Design Guide Link
amateur	20%	Portable, easy to operate, and prevents waist strain	Bend forward 150+ times per session	Lightweight design and handle assistance reduce lumbar load
Professional Athletes	30%	Efficient storage, no ball jamming, and adaptable to various spaces	Traditional ball retrieval disrupts training rhythm (20-30 times per session)	Roller shaft with radial rod anti-sticking mechanism and 15° inclined track for efficiency
Venue Manager	50%	Durable, suitable for soft and hard floors, easy to clean	The existing equipment is only suitable for hard floors and is prone to damage	Planetary gear power system, anti-deformation storage structure

This chart analyzes the distinct needs of three user groups in badminton multi-ball training: amateurs, professional athletes, and venue managers. By identifying these needs as key pain points, the design achieves deep integration between product features and various user scenarios. The 20% amateur group prioritizes portability, ease of operation, and waist protection. The 30% professional athlete group focuses on storage efficiency and multi-venue adaptability. Meanwhile, the 50% venue manager group emphasizes equipment durability and compatibility with both soft and hard flooring surfaces.

In conclusion, the chart provides a direction for the functional division of this design by analyzing the differentiated needs and pain points of the three target groups.

User Requirement Extraction and Kano Model Analysis.

Within the scope of user needs for badminton storage devices, we conducted in-depth research and analyzed them using the Kano model, dividing them into three levels: basic, expected, and exciting, with corresponding design priorities.

The basic requirement is the core of the product that directly affects the basic threshold of user satisfaction; the expectation requirement is linearly positively correlated with satisfaction; the excitement requirement with hidden characteristics can improve the experience satisfaction level after implementation.

Regarding the design weight distribution of this product, a quantitative analysis approach can be employed to achieve clear allocation. In terms of basic requirements, operational convenience accounts for 45% of the proportion. For desired functionalities, efficiency enhancement represents 30%, while innovative features contribute 25%

to unlocking potential value. By implementing this hierarchical system in design practices, we ultimately finalized a tiered solution: To address the pain point of bending over, a semi-automatic picking mechanism is adopted, complemented by adjustable-capacity modules and intelligent expansion interfaces. This ensures comprehensive coverage of efficiency requirements and optimal resource allocation across all dimensions.

4 Innovative Ergonomic Design of Storage Devices

4.1 Working Principle and Overall Scheme Design

The primary function of this equipment is to efficiently collect badminton balls, specifically designed for use in training courts. Its operational mechanism works as follows: When activated, the ball-collecting machine's dual wheels rotate to drive the rollers. The radially arranged rods (spaced 40mm apart) on the rollers precisely align with the shuttlecock's waist position. Through this rotation, the shuttlecock is guided to the sorting plate while maintaining its downward orientation. The shuttlecock then passes through the sorting plate's interference mechanism, separating from the collection device and entering the next module. The sorting plate features a single-row semi-circular tube design that mimics the shuttlecock's barrel structure. The storage module employs a single-barrel collection system, utilizing 70mm-diameter barrels for ball storage. The planetary gear mechanism serves as the core component, providing power to the shuttlecock storage device. This gear system integrates with the dual wheels and rollers through a differential design, enabling planetary gear operation through dual-wheel rotation. When a single barrel reaches its capacity limit, users can replace it for continued storage. The shuttlecock storage system consists of a collection module, sorting plate, storage module, planetary gear, roller shaft, and radially arranged rods, forming a modular ball-guiding roller shaft system. The complete assembly diagram is shown in Figure 1.

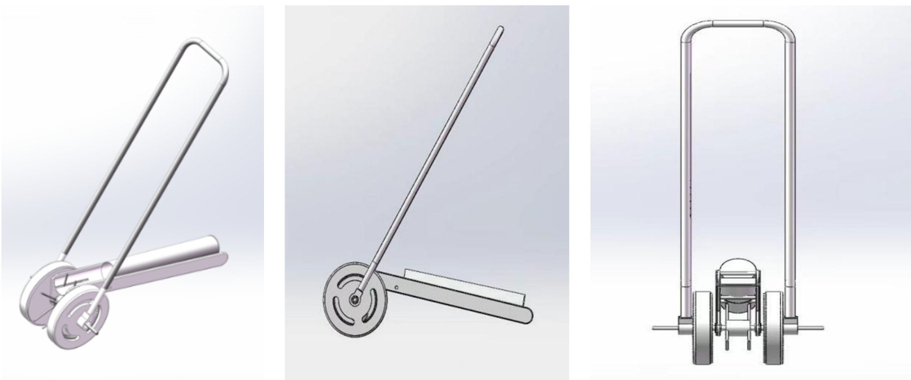

Fig. 1. Overall assembly of the badminton storage device

Module Design.

The structure design of the badminton storage device is divided into three main parts, namely, the equipment start and ball picking part, the sorting and guidance part and the storage module part. The specific distribution is shown in Figure 2.

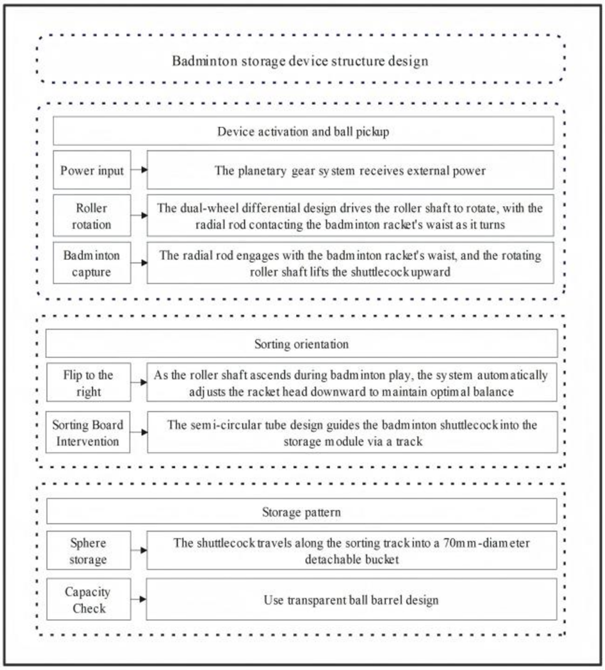

Fig. 2. Structure design of badminton storage device

Collection Module Design.

The badminton storage device primarily serves as a ball retrieval system. Its retrieval mechanism employs a combination of a roller shaft and radial rods, featuring a ball-dialing roller shaft capable of picking up six small balls simultaneously while preventing damage during retrieval. The planetary gears installed on the inner side of the dual wheels ensure uniform rotational motion of the roller shaft. As shown in Figure 3, the ball-dialing roller shaft is illustrated, while the integrated dual-wheel and planetary gear assembly is depicted.

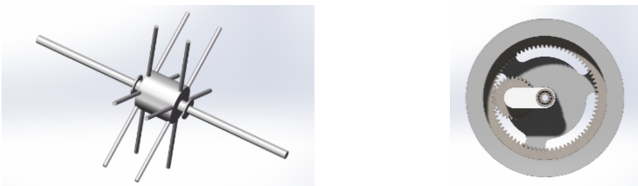

Fig. 3. Ball Rollers and Combination of dual wheels and planetary gears

Sorting and Storage Module Design.

The sorting and storage system comprises two primary modules: a specialized design for separating badminton balls, and a dedicated storage system. The collection port features a cylindrical tube mimicking the structure of a standard badminton bucket. The storage track, constructed from a smooth, low-friction material, guides separated balls along a radial rod, allowing them to accumulate within the detachable bucket. This modular design enables easy removal and replacement of the bucket, as illustrated in Figure 4.

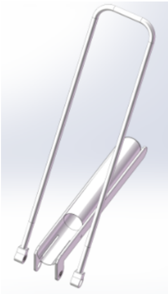

Fig. 4. Featherball Storage Module

Power Module Design.

The power module is the core of this design, and its operation stability and transmission efficiency directly determine the working reliability and user experience of the badminton storage device. The power transmission path is shown in Figure 5.

The integrated design of the power module employs a transmission system combining a bevel gear with planetary gears, where the bevel gear's output shaft is rigidly connected to the planetary gear's sun gear. This configuration enables power input into the planetary system. By securing either the planetary carrier or the ring gear while using the other as the output shaft, specific gear ratios can be achieved. The planetary gears, bevel gear, and paddle roller shaft form a complete transmission system. The power module of the badminton storage device is illustrated in Figure 6.

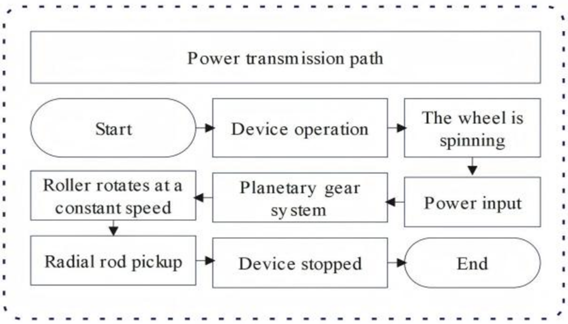

Fig. 5. Power output path

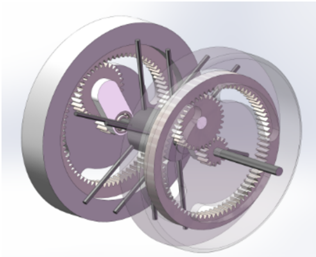

Fig. 6. Power module of the badminton storage device

5 Performance Advantages of Badminton Storage Device

This design combines innovative mechanical structure design with human factors engineering to create a new badminton storage device with certain performance advantages.

At the heart of this design lies the collection module, which innovatively integrates rollers with radial rods spaced precisely 40mm apart to secure the shuttlecock's midsection. This configuration achieves a 95%+ success rate while maintaining the ideal downward orientation of the shuttlecock head. The sorting mechanism employs a single-row semi-circular track with a 15° horizontal tilt angle, complemented by guide partitions that allow gravity-assisted descent for rapid sorting. The power module combines wheels with planetary gear systems, requiring minimal user effort to operate and significantly reducing operational strain. Featuring a lightweight design, this system demonstrates 80% enhanced portability compared to conventional equipment. The adjustable rollers paired with anti-slip pads ensure stable performance across diverse surfaces including wooden floors and synthetic tracks.

This design effectively solves the problems of frequent bending and low efficiency in the traditional way of picking up the ball. In addition, the modular design also reserves intelligent interfaces to support future upgrades and other expansion functions, ensuring the perfect balance between low cost and advantages in mass production to achieve efficient collection, labor-saving operation and multi-scenario adaptation.

6 Conclusions

This study, grounded in human factors engineering principles, has developed an innovative storage system that resolves the "efficiency bottleneck" in multi-ball training for badminton. The design integrates three core innovations: a roller-shaft radial rod assembly, a planetary gear differential power system, and a 15° inclined sorting track. These components collectively achieve high efficiency, reduced physical strain, and minimal equipment damage. Simulation tests demonstrate over 95% collection success rate, while structural optimization reduces operator lumbar load by approximately 32.5% and maintains the device's weight within 1.8±0.2kg. This breakthrough effectively addresses the fundamental challenges of traditional ball-picking methods, including low efficiency and frequent operator fatigue.

This study achieves a deep integration of human factors engineering and sports equipment design, transcending the limitations of existing products that focus solely on basic functions. Through ingenious mechanical designs such as modular ball-dribbling rollers, combined with Kano model-guided demand quantification, it ensures dual improvements in functionality and user experience at low cost. This provides a new paradigm for the professional and humanized development of training auxiliary equipment.

The next phase aims to further integrate IoT and sensor technologies to develop intelligent modules with path planning and data management capabilities. We will explore the adaptability of this design principle for training aids in sports like tennis and table tennis, and conduct long-term user studies to evaluate its practical benefits in high-level training systems.

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