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Article

Research on the application and technical optimization of combining biomechanics and multi-ball training method in tennis teaching

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Abstract: With the growing popularity of tennis, improving players' technical skills has become a key focus in tennis instruction. This study investigates the application of a multi-ball training method integrated with biomechanical principles in tennis teaching and its effect on technical optimization. A total of 40 university tennis enthusiasts participated in this research, divided into an experimental group (EG) and a control group (CG) using a double-blind randomized controlled trial. The experimental group used a data-driven intelligent training system that incorporated sports biomechanics analysis and provided real-time feedback, while the control group adhered to traditional teaching methods. The results showed that the experimental group significantly outperformed the control group in biomechanical parameters such as swing speed, shot accuracy, and body stability. Furthermore, the experimental group demonstrated improvements in cognitive neural response, sports anxiety, and achievement motivation. By combining biomechanics with the multi-ball training method, this approach optimizes technical performance, enhances motor control, and improves training efficiency. This study provides new scientific evidence and practical insights for tennis instruction.

Keywords: tennis teaching; multi-ball training method; biomechanics; intelligent training system; motor control; cognitive neural response; training optimization

1. Introduction

Tennis is a sport with a rich history, originating in 12th-century France. Initially, monks played the game by striking a ball with their palms in open spaces, and over time, it evolved into a recreational activity. By the mid-14th century, tennis had spread from France to England, becoming a popular pastime among the aristocracy of the court. During the 16th and 17th centuries, tennis gained prominence in both the French and English courts, symbolizing social status [1]. In 1873, British player M. Wingfield refined the rules of tennis, standardizing the court dimensions and net height, marking the beginning of modern tennis [2]. The All England Croquet Club established formal competition rules in 1875, and in 1877, Wimbledon hosted the first grass-court tennis championship [3]. The sport continued to evolve, with slight adjustments made to the net height in 1884, and tennis gradually became accessible to the general public, growing into a global phenomenon [4]. The formation of the International Tennis Federation (ITF) in 1912 further solidified tennis as an international sport [5]. China joined this global tennis community in 1980 when the Chinese Tennis Association became a member of the ITF [6].

Tennis employs a unique scoring system based on increments of 15, which is inspired by the sextant used in astronomy [7]. Originally, a set consisted of four games, with each game comprising four points; however, this was later modified to six games per set [8]. Since Wingfield's refinements in 1873, tennis has become one of the most widely played sports globally [9,10]. The sport made its debut as an official Olympic event in 1896 [11], and it was reinstated in 1988, allowing professional players to compete [12]. Chinese tennis experienced significant development in the late 20th century, with players like Zheng Jie and Li Na achieving outstanding success on the international stage [13–15]. Today, tennis continues to grow in popularity in China and has become an important sport for fitness and recreation [16].

As the number of tennis enthusiasts continues to grow, the development of efficient methods for teaching tennis skills has become a critical issue in sports education. Research has demonstrated that the multi-ball training method is effective in improving tennis skills, especially in terms of reaction speed and shot accuracy [17,18]. Additionally, integrating biomechanical principles into training offers both a theoretical foundation and practical guidance for optimizing athletic performance. Analyzing stroke mechanics, as the number of tennis enthusiasts continues to grow, the development of efficient methods for teaching tennis skills has become a critical issue in sports education. Research has demonstrated that the multi-ball training method is effective in improving tennis skills, especially in terms of reaction speed and shot accuracy [17,18]. Additionally, shot efficiency and precision [19,20]. The incorporation of multidimensional training—such as strength, speed, and agility drills—further strengthens players' overall competitive abilities [21–23]. Modern tennis education increasingly emphasizes personalized, systematic, and progressive training strategies, allowing learners to develop and refine their skills in the most efficient manner possible [24–30].

This study aims to explore the application of the multi-ball training method in tennis instruction and to optimize training strategies using biomechanical principles. By integrating biomechanics with multi-ball training, this research seeks to establish a more scientific and efficient approach to tennis training, thereby enhancing players' technical proficiency and overall performance.

2. Research subjects

This study selected 40 amateur university tennis players from a tennis club at a university in Guangdong Province as research subjects. All participants were aged between 18 and 25, in good health, and had no history of major sports injuries. A double-blind randomized controlled experimental design was employed, with participants divided into an experimental group and a control group based on natural conditions and sports experience, with 20 individuals in each group.

The experimental group (EG, n = 20) participated in personalized movement optimization training using a data-driven intelligent training system that integrated sports biomechanics analysis and computer vision technology. Real-time feedback adjustments were implemented based on data collected from accelerometer sensors and electromyographic (EMG) signals. In contrast, the control group (CG, n = 20) engaged in a traditional demonstration-based teaching method, where professional coaches conducted standardized movement training. This instructional approach primarily depended on visual imitation and repetitive practice, lacking real-time data feedback.

Before the experiment, all participants completed baseline assessments of physical fitness, psychological evaluations (including sports anxiety and achievement motivation), and tennis skill assessments. The training program lasted for eight weeks, consisting of three sessions per week, each lasting 90 min. Data collection focused on five key aspects throughout the study (**Table 1**):

(1) Sports biomechanical parameters, including swing speed, shot accuracy, and body stability.

(2) Variations in physiological signals, such as the root mean square (RMS) of EMG signals and heart rate variability.

(3) Cognitive neural responses, primarily analyzing changes in EEG alpha (α) and beta (β) waves.

(4) Psychological evaluations, including the Sports Anxiety Scale (SAS) and the Achievement Motivation Scale (AMS).

(5) Changes in physical performance, covering indicators such as sprint speed, grip strength, and flexibility.

Table 1. Statistical summary of participants' baseline characteristics (M ± SD).

Group	Age (years)	Height (cm)	Weight (kg)	Sports experience (years)	Sports anxiety (SAS)	Achievement motivation (AMS)
Experimental group	21.5 ± 1.3	175.2 ± 6.1	67.5 ± 8.3	1.2 ± 0.9	38.2 ± 4.5	27.8 ± 3.7
Control group	21.3 ± 1.5	174.8 ± 5.9	66.8 ± 7.5	1.0 ± 1.1	39.1 ± 4.8	26.5 ± 3.9

The participants in both the experimental and control groups exhibited no significant differences in fundamental characteristics, including age, height, weight, and sports experience (p > 0.05). This finding indicates that the initial physical conditions of both groups were relatively balanced, thereby ensuring the comparability and scientific validity of the experimental results.

Table 2. Comparison of sports biomechanics parameters (After 8 weeks).

Group	Swing speed (m/s)	Stroke accuracy (%)	Body stability (%)	EMG RMS (mV)	Heart rate variability (ms)
Experimental group	32.5 ± 2.3	84.7 ± 6.5	91.3 ± 4.2	0.87 ± 0.12	52.3 ± 6.8
Control group	29.8 ± 2.6	76.5 ± 7.1	85.2 ± 5.3	0.79 ± 0.15	47.6 ± 7.2
p-value	0.003**	0.012**	0.017*	0.041*	0.028*

Note: * p < 0.05; ** p < 0.01.

Table 3. Comparison of cognitive and motor focus parameters.

Group	*α* waves (μV^2)	*B* waves (μV^2)	Cognitive load (%)	Motor focus (%)
Experimental group	8.7 ± 1.1	5.2 ± 0.9	32.1 ± 5.4	85.3 ± 4.8
Control group	7.5 ± 1.4	4.6 ± 1.2	38.9 ± 6.2	78.5 ± 5.2
p-value	0.021*	0.034*	0.018*	0.009**

Note: * p < 0.05; ** p < 0.01.

Additionally, there were no significant differences in sports anxiety (SAS scores) and achievement motivation (AMS scores) between the two groups at the baseline level (p > 0.05), indicating that their psychological factors were well-matched prior to the experiment. This finding confirms that any observed effects during the experiment can be primarily attributed to differences in training methods rather than initial disparities in individual psychological states or physical fitness (see **Tables 2** and **3**).

The cognitive neural response test results for the experimental group indicated superior brain relaxation, attention focus, cognitive load reduction, and sports concentration compared to the control group, further validating the positive impact of the intelligent training system on motor control and cognitive performance.

The results of the cognitive neural response test for the experimental group demonstrated enhanced brain relaxation, improved attention focus, reduced cognitive load, and increased sports concentration compared to the control group. These findings further validate the positive impact of the intelligent training system on motor control and cognitive performance.

Firstly, the experimental group demonstrated a significant increase in alpha (α) waves (p = 0.021), indicating a higher level of post-exercise brain relaxation and reduced stress associated with training. This finding suggests that the intelligent training system aids students in better adapting to the training environment, alleviating anxiety, and enhancing the fluidity and confidence of their movements. Secondly, the increase in beta (β) waves (p = 0.034) reflected greater attentional focus during training. This suggests that the real-time feedback mechanism of the intelligent training system effectively enhances students' concentration, allowing them to make more precise adjustments in their strokes and improve the stability of their technical execution.

Additionally, the cognitive load of the experimental group significantly decreased (p = 0.018), demonstrating that the intelligent training system reduces the cognitive resources required during movement execution, enabling students to perform technical actions more efficiently. This effect is likely attributable to the system's instantaneous data analysis and personalized adjustments, which minimize uncertainty in the learning process and alleviate additional cognitive burdens, thereby facilitating a more automated mastery of technical skills. Finally, the sports concentration of the experimental group showed a significant improvement (p = 0.009), indicating that data feedback not only optimized motor control but also enhanced training efficiency. Increased sports concentration allows students to focus more on executing techniques during training, thereby reducing ineffective practice and improving learning outcomes.

Overall, the cognitive neural benefits observed in the experimental group further validate the scientific credibility and practical utility of the intelligent training system in optimizing motor control, enhancing focus, and alleviating sports-related stress.

Table 4. Sports psychology assessment.

Group	Sports anxiety (SAS)	Achievement motivation (AMS)	Training satisfaction (%)
Experimental group	32.4 ± 3.2	34.7 ± 3.9	92.3 ± 5.1
Control group	37.8 ± 4.5	29.5 ± 4.2	81.6 ± 6.8
p-value	0.015*	0.007**	0.002**

Note: * $p < 0.05$; ** $p < 0.01$.

As shown in **Table 4**, the experimental results indicate that the experimental group significantly outperformed the control group in terms of sports anxiety, achievement motivation, and training satisfaction. These findings suggest that the intelligent training system not only optimizes technical training outcomes but also positively influences students' psychological well-being, thereby offering a more comprehensive approach to sports education.

Firstly, the experimental group demonstrated a significant decrease in sports anxiety ($p = 0.015$), highlighting the advantages of the intelligent training system in reducing sports-related stress. Traditional training methods, which often rely on verbal instructions and repetitive practice, can induce anxiety due to uncertainty and delayed feedback. In contrast, the intelligent system provides real-time, data-driven feedback, enabling students to clearly comprehend their progress and mitigating the psychological pressure associated with technical instability. This support fosters a more stable mental state, allowing students to train with greater focus and less stress.

Secondly, the experimental group exhibited a significant increase in achievement motivation ($p = 0.007$), suggesting that modern, data-driven teaching methods are more effective in boosting students' enthusiasm for sports. The intelligent training system offers instant feedback and helps students visualize their progress, thereby boosting their motivation to improve. Moreover, personalized training allows students to adjust their pace according to individual needs, which reduces frustration and fosters a greater sense of autonomy. In contrast, traditional training methods, which lack real-time data feedback, often leave students unable to track their progress, resulting in disengagement and decreased motivation.

Finally, the training satisfaction rate in the experimental group was significantly higher (92.3%, $p = 0.002$) compared to the control group, reflecting strong approval of the intelligent training system's teaching methods and effectiveness. This higher satisfaction indicates that students not only experienced improved learning outcomes but also found the training process more engaging and rewarding. The personalized feedback, combined with more efficient training, increased students' commitment and enthusiasm, ultimately improving the overall training experience.

In conclusion, the significant improvements in psychological adaptability, achievement motivation, and overall satisfaction in the experimental group validate the effectiveness of the intelligent training system. By optimizing both technical and psychological aspects of training, this system offers a comprehensive solution for enhancing sports learning outcomes and fostering a positive, engaging training environment.

3. Research methods

3.1. Literature review method

This study conducted a comprehensive review of both domestic and international literature on the instruction of the tennis forehand stroke, emphasizing the learning characteristics, technical training methods, and teaching models for amateur tennis players. The review encompassed four main areas: teaching methodology, sports biomechanics, cognitive and psychological aspects, and the application of artificial intelligence (AI) in training and data analysis. First, studies on teaching methodology examined fundamental techniques, the influence of different grip styles, and comparative analyses of training methods, thereby providing a foundation for optimizing instructional strategies. Second, research in sports biomechanics focused on swing paths, force transmission, and changes in electromyographic signals, offering insights to enhance stroke efficiency and reduce the risk of injury in experimental design.

Additionally, the review explored cognitive and psychological factors, such as sports cognition, achievement motivation, concentration, and psychological stress, to understand how these elements influence learning outcomes. Incorporating feedback and motivation mechanisms into the experimental group's training methods aimed to enhance both physical and mental engagement. Furthermore, the role of AI in tennis training was investigated, focusing on the use of computer vision, motion capture systems, and intelligent data feedback. These technologies facilitate real-time analysis and data-driven insights, thereby supporting the experimental group's approach in delivering personalized, scientifically grounded feedback. This comprehensive literature review established a robust theoretical and methodological foundation for the experimental teaching design, data analysis, and evaluation, ultimately contributing to the overall effectiveness of the study's tennis training approach.

3.2. Teaching experiment design

This study employed a comparative experimental method, conducting a five-week (ten-session) training program for two groups of participants based on pre-planned instructional content, methods, and approaches. The control group (CG, n = 20) followed the traditional teaching method that focused on a fixed instructional process and standardized practice models. This approach emphasized teacher demonstrations and student imitation, with a strong focus on repetitive practice to master technical movements. In contrast, the experimental group (EG, n = 20) utilized an intelligent training system combined with a multi-ball training method. This approach optimized teaching strategies through data feedback and implemented personalized training tailored to individual characteristics, thereby enhancing learning outcomes, improving training efficiency, and strengthening technical proficiency.

3.2.1. Control group teaching method

The control group followed a traditional tennis teaching approach, which encompassed a blend of theoretical instruction, fundamental technical training, and practical exercises. The instructional process was divided into several phases, starting with an overview of tennis to help students develop a foundational understanding of the sport.

In the theoretical instruction phase, students were introduced to essential aspects of tennis, including the game rules, court layout, and equipment usage. This provided a clear framework for understanding the sport's basic principles. Next, during grip training, students learned about three common grip styles: the Eastern grip (also known as the handshake grip), which is ideal for beginners and enhances forehand power; the Continental grip (hammer grip), which allows for quick transitions between forehand and backhand strokes but requires more wrist strength; and the Western grip, which is favored for offensive play, particularly when dealing with high-bouncing balls.

During the technical training phase, students were taught the ready position, focusing on proper stance and weight distribution to ensure balance and stability during strokes. Footwork training was also emphasized to help students quickly adjust their positioning in preparation for forehand strokes. In the forehand stroke segment, the full motion sequence—backswing, swing, and follow-through—was broken down into smaller components, starting with shadow swings without a ball and progressing to rally drills aimed at enhancing stroke consistency and stability. Due to space limitations, some drills included wall-hitting exercises, where students practiced rebound strokes to improve their consistency. Paired rally drills were also incorporated to help students develop stroke rhythm and adapt to match scenarios. The teaching process followed a step-by-step approach, emphasizing demonstration and imitation, reinforced by repetitive practice to ensure that students mastered the fundamental techniques.

3.2.2. Experimental group teaching method

The experimental group utilized an intelligent training system that incorporated ball familiarity exercises, with the goal of developing both cognitive and motor control abilities to enhance technical mastery and adaptability in match situations. The training program was structured around two primary components: personalized grip training and ball familiarity drills, which work in tandem together to optimize students' skills.

In the personalized training program, students were given the freedom to select their preferred grip style based on their individual habits, with the objective of optimizing grip technique through real-time feedback from an intelligent training system. This system provided data-driven insights to assist students in refining their grip, enabling them to adjust and improve based on their performance. Furthermore, students were encouraged to adopt the semi-Western grip, which is recognized for providing enhanced stability and power control. This adjustment aimed to improve forehand stroke accuracy and shot quality, allowing students to execute more consistent and powerful strokes. The ball familiarity training program consisted of a series of progressively challenging drills designed to improve students' feel for the ball and improve their coordination. The first stage involved students jogging while balancing a ball on their racket, which helped them practice grip stability and control. In the second stage, self-tossing and catching drills were introduced to help students become more familiar with ball bounce and develop their quick reactions. The third stage focused on reaction speed through a partner-based exercise, where one student predicted and caught a randomly placed ball. This drill enhanced both anticipation and reaction time. The fourth stage included racket bouncing drills, where students alternated between forehand and backhand bounces, practicing various bounce heights and lateral ball control to further develop hand-eye coordination. Finally, forehand stroke training progressed from controlled short-distance strokes to full-court rally practice, improving shot accuracy and consistency. Throughout all stages, the intelligent training system provided real-time data feedback on grip technique, ball control, stroke rhythm, and movement coordination, enabling students to optimize their performance and achieve greater technical progress in a shorter timeframe.

3.3. Multi-ball training method

The experimental group employed a data-driven multi-ball training method that combined coach-fed balls with an intelligent feedback system to optimize training procedures and enhance learning efficiency. The training program encompassed various feeding methods, clear training objectives, and the application of the intelligent feedback system, ensuring that students received precise technical guidance and real-time adjustments throughout their forehand stroke training. The feeding methods used in the experimental group included two distinct modes: fixed-point feeding and dynamic feeding. In fixed-point feeding, students practiced forehand strokes from a predetermined position along the baseline or service line, focusing on developing stroke consistency and stability. This approach allowed students to refine their technique without the added complexity of movement. Conversely, dynamic feeding required students to execute forehand strokes while in motion, aiming to improve footwork agility, coordination, and adaptability—skills that are crucial for real match situations where movement and shot execution must be seamlessly integrated.

The intelligent feedback system played a pivotal role in refining the training process by offering precise analysis of students' stroke timing, hand control, and shot accuracy. It used sensors to monitor swing timing, helping to optimize stroke rhythm and ensure that students executed their shots at the ideal moment. Additionally, the system tracked the impact points and power of each stroke, assessing hand control and enhancing shot speed and spin management. The computer vision component further analyzed shot placement, providing students with immediate feedback to improve shot stability and accuracy. Moreover, the system included motion trajectory analysis, electromyographic signal monitoring, and real-time feedback. Cameras captured the swing trajectories, enabling an analysis of stroke paths and shot angles. Meanwhile, electromyographic sensors monitored muscle activation patterns in the forearm and shoulder to improve force generation and power output. After each session, the system generated detailed data reports, enabling students to make targeted adjustments in subsequent sessions, thus improving both the quality of training and learning efficiency.

Through this data-driven approach, the experimental group demonstrated substantial improvements in shot accuracy, footwork coordination, and reaction speed. Additionally, by optimizing muscle force application and refining stroke techniques, the intelligent feedback system enabled students to make significant technical advancements in a short time. This integrated method highlighted the potential of combining multi-ball training with intelligent technology for more efficient and targeted tennis training.

Control group training method

The control group did not employ multi-ball training but instead used a traditional single-ball practice method, which was more basic and relied primarily on individual stroke repetitions. The training focused on developing swing mechanics and shot consistency, with students refining standard stroke techniques through repeated practice. However, due to the lack of support from data analysis, the training process could not quantitatively assess or optimize stroke rhythm, power control, or shot accuracy.

Additionally, this training approach was relatively simplistic, relying mainly on coach demonstrations and verbal feedback for corrections, lacking intelligent and personalized guidance. As a result, students' perception of their own technical progress was relatively delayed. Since the teaching model followed a fixed structure, it did not provide real-time data feedback, making improvements in stroke consistency and shot quality slower compared to the experimental group (**Table 5**).

Table 5. Summary of experimental design.

Group	Teaching method	Main training approach	Data feedback	Training optimization mechanism
Experimental group	Intelligent training system + Multi-ball practice	Multi-ball feeding + Sports biomechanics analysis	Yes (Computer vision + Sensors)	Yes (Real-time adjustment of teaching plan)
Control group	Traditional teaching method	Single-ball practice + Wall practice	No	No

This study introduces an advanced tennis training system that combines intelligent training technology, the multi-ball training method, cognitive and psychological interventions, and data-driven optimization to enhance both the training effectiveness and the overall learning experience for amateur tennis enthusiasts. By integrating these innovative strategies, this research aims to address the limitations of traditional teaching methods and provide a more personalized and practical approach to tennis training.

The study introduces an advanced training system that integrates computer vision, electromyographic signal analysis, and real-time feedback technology to monitor and analyze students' training processes. This system provides precise data support, allowing coaches to optimize teaching strategies tailored to each student's technical proficiency. With continuous, data-driven insights, students receive personalized guidance to address their weaknesses and refine their techniques, ultimately improving training efficiency and effectiveness. Additionally, the experimental group utilizes the multi-ball training method, where coaches deliver balls at a high frequency, helping students improve their stroke rhythm, reaction speed, and footwork coordination. Compared to traditional training approaches, multi-ball training offers more hitting opportunities in a shorter time frame, thereby enhancing motor control and making practice more dynamic and relevant to match situations.

This study integrates sports psychology assessments, focusing on the impact of psychological factors such as sports anxiety, achievement motivation, and training satisfaction on learning outcomes. By reducing uncertainty during training and offering clearer feedback, the intelligent training system alleviates sports anxiety while enhancing students' sense of achievement and engagement in training. Additionally, the data-driven optimization strategy facilitates the development of personalized training plans. Through AI-driven data analysis, the system dynamically adapts to students' athletic performance and physiological data, adjusting instructional priorities to address the specific needs of learners at different skill levels. This adaptive approach ensures that each student receives the most appropriate training plan, thereby improving their overall learning outcomes.

In conclusion, this study establishes a more efficient and scientifically grounded tennis training system by combining intelligent technology, optimized multi-ball training, psychological regulation, and precise data analysis. The combination of these elements offers a comprehensive and personalized training experience, paving the way for innovative approaches to future tennis teaching and training models.

4. Experimental results analysis

4.1. Comparison of experimental results

After five weeks of training, both groups underwent a forehand rally test to evaluate the impact of different training methods on forehand performance. To ensure the reliability and consistency of the test results, the experiment implemented strict control measures, including standardized testing procedures, control of variables, and meticulous data recording.

For the testing method, professional coaches conducted uniform ball feeding, with each student performing a 10-ball rally test. The number of consecutive successful hits was recorded, and the average value was used as the final score to assess stroke stability and technical proficiency. To ensure variable control, the test maintained consistent ball angles, speeds, and landing points throughout, minimizing external environmental influences on the results and ensuring data comparability.

Additionally, the experiment utilized a computer vision tracking system for data recording, accurately counting each student's successful hits to enhance data precision and objectivity. This technological approach not only reduced human error but also provided more detailed data analysis, thereby supporting the quantitative evaluation of the experimental results (**Table 6**).

Table 6. Comparison of consecutive forehand stroke count.

Group	Average consecutive stroke (time)	Standard deviation (SD)	Improvement rate (%)
Experimental group	18.2 ± 3.5	3.5	+203%
Control group	6.0 ± 2.1	2.1	-
Mean difference	12.2 times	-	-

The experimental results indicate that the experimental group demonstrated a significantly higher number of consecutive forehand strokes compared to the control group, with an average increase of 12.2 strokes and a 203% improvement in stroke success rate. This result clearly demonstrates that the combination of the intelligent training system and the multi-ball training method effectively enhances students' stroke stability, improves training efficiency, and enables them to master more precise stroke techniques in a short period. Furthermore, standard deviation analysis shows that the experimental group had a lower standard deviation (SD = 3.5) than the control group, indicating higher internal stroke stability and reduced individual differences. This suggests that the intelligent training system has a significant advantage in reducing technical variability, allowing students to develop a stable stroke rhythm more quickly and maintain a higher level of consistency during training.

In contrast, the control group showed slower progress, achieving an average of only 6.0 consecutive strokes, which is significantly lower than that of the experimental group. This indicates that traditional teaching methods have limited effectiveness in rapidly improving the skills of amateur tennis players. Without real-time data feedback, students find it challenging to make precise adjustments to their movements, leading to slower skill acquisition and minimal improvement in stroke stability.

In conclusion, integrating the intelligent training system with the multi-ball training method significantly enhances students' stroke continuity, stability, and success rate. This approach provides amateur tennis players with a more efficient learning pathway, enabling them to achieve substantial technical breakthroughs in a shorter time frame.

4.2. Sports biomechanics analysis

Beyond stroke success rate, this study also measured students' swing speed, stroke accuracy, and body stability to analyze further improvements in sports biomechanics between the two groups (**Table 7**).

Table 7. Improvement in sports biomechanics parameters (Pre- and post-experiment comparison).

Group	Swing speed (m/s)	Stroke accuracy (%)	Body stability (%)	Stroke angle error (°)
Experimental group	34.5 ± 2.6 (↑21%)	89.7 ± 4.3 (↑19%)	94.3 ± 3.2 (↑23%)	3.2 ± 0.7 (↓45%)
Control group	30.2 ± 2.8 (↑7%)	78.5 ± 5.7 (↑8%)	86.1 ± 4.5 (↑9%)	5.8 ± 1.1 (↓12%)
p-value	0.007**	0.015*	0.011*	0.004**

Note: * $p < 0.05$; ** $p < 0.01$.

The experimental group demonstrated significant improvements compared to the control group in key biomechanical performance indicators, including swing speed, stroke accuracy, body stability, and shot angle control. These findings further validate the effectiveness of integrating the intelligent training system with the multi-ball training method in enhancing tennis techniques. This combined approach not only optimizes stroke mechanics but also improves overall athletic performance.

First, the swing speed of the experimental group increased by 21%, surpassing that of the control group by 14%. This underscores the significant impact of multi-ball training on stroke power. This method, which involves continuous stroke practice, allows students to accumulate a high volume of repetitions in a short time, thereby reinforcing muscle memory and power control. Consequently, participants in the experimental group were able to produce more efficient and stable swings, ultimately improving their overall performance.

The stroke accuracy of the experimental group improved by 19%, outperforming the control group by 11% ($p < 0.05$). This improvement can be attributed to the real-time feedback provided by the intelligent training system, which helps students optimize shot control. Through data analysis, students were able to make immediate adjustments to their swing angle, power, and impact point, thereby reducing ineffective strokes and improving the precision and stability of their shots. Similarly, body stability showed a 23% improvement in the experimental group, compared to only 9% in the control group, indicating the significant impact of multi-ball training on balance and coordination. This approach helps students develop better core stability and agility, which enhances their resistance to external disturbances during play.

Finally, the shot angle deviation in the experimental group was reduced by 45%, demonstrating the effectiveness of the intelligent training system in improving shot direction control. By using computer vision analysis and trajectory tracking, students can visualize their swing paths and ball landing points, leading to greater consistency in their shots. These improvements in technique and control allow players to minimize ineffective strokes and off-target hits. In conclusion, the significant advantages of the experimental group across multiple key technical indicators underscore the scientific and practical value of combining intelligent training systems with multi-ball training. This method enables amateur tennis players to master their techniques more efficiently, boost their competitive performance, and support the modernization of tennis instruction.

4.3. Sports psychology assessment

Considering the impact of psychological factors on athletic performance, this study measured both groups' sports anxiety levels (SAS scale) and training satisfaction before and after the experiment (**Table 8**).

Table 8. Changes in sports psychology.

Group	Sports anxiety score (SAS)	Training satisfaction (%)	Achievement motivation score (AMS)
Experimental group	29.5 ± 3.8 (↓22%)	91.3 ± 4.2 (↑32%)	36.5 ± 3.7 (↑27%)
Control group	35.8 ± 4.2 (↓7%)	79.2 ± 5.3 (↑13%)	31.2 ± 4.1 (↑10%)
p-value	0.008**	0.003**	0.012*

Note: * $p < 0.05$; ** $p < 0.01$.

The experimental group showed significant advantages over the control group in terms of sports anxiety, training satisfaction, and achievement motivation. This indicates that the combination of the intelligent training system and the multi-ball training method not only optimizes technical improvement but also positively influences psychological outcomes. First, the sports anxiety level in the experimental group decreased by 22%, which was 15% higher than the reduction observed in the control group. This suggests that the intelligent training system effectively alleviates tension during strokes. Traditional methods often lack real-time feedback, leaving students feeling uncertain due to technical instability and unclear progress. In contrast, the intelligent system provides data-supported insights into individual progress, reducing uncertainty and allowing students to maintain a more stable psychological state. This, in turn, helps them stay focused and confident during training.

Secondly, training satisfaction in the experimental group reached 91.3%, significantly surpassing the 79.2% observed in the control group. This highlights that multi-ball training better meets students' needs and enhances engagement. By increasing the frequency of practice, the multi-ball method enables students to gain more practical experience in a shorter period. Additionally, real-time feedback from the intelligent system enables students to quickly correct mistakes, thereby improving learning efficiency and making the training process more scientific, effective, and engaging. Furthermore, achievement motivation in the experimental group increased by 27%, which is 17% higher than the improvement seen in the control group. This underscores the ability of multi-ball training to boost students' confidence in learning tennis. With the intelligent system, students see noticeable progress within a short timeframe, enhancing their sense of self-efficacy and motivating them to train with greater enthusiasm and persistence.

In conclusion, the experimental group demonstrated significant improvements in psychological adaptability, learning satisfaction, and motivation. This provides compelling evidence that the integration of the intelligent training system and multi-ball training not only enhances tennis skills but also positively impacts students' psychological well-being. This approach fosters a relaxed and confident learning environment, allowing students to improve more effectively.

4.4. Summary of training outcomes

Table 9 presents a comparison of key training performance indicators between the experimental group (EG), which participated in multi-ball training, and the control group (CG), which followed traditional training methods. The experimental group showed substantial improvements across all dimensions. In terms of technical performance, the EG demonstrated a remarkable increase in average stroke count (18.2 times vs. 6.0 times in the CG), reflecting a 203% improvement. This was accompanied by notable enhancements in swing speed (+21%), stroke accuracy (+19%), and body stability (+23%), underscoring the effectiveness of multi-ball training in improving stroke mechanics, overall performance, and stability during play.

Table 9. Comprehensive training performance comparison.

Training dimension	Key indicator	Experimental group (EG)	Control group (CG)	Improvement effect
Technical performance	Average stroke count	18.2 times	6.0 times	+203%
Athletic ability	Swing speed	34.5 m/s	30.2 m/s	+21%
	Stroke accuracy	89.7%	78.5%	+19%
	Body stability	94.3%	86.1%	+23%
Psychological state	Sports anxiety	29.5 (Low)	35.8 (High)	−22%
	Training satisfaction	91.3%	79.2%	+32%
	Achievement motivation	36.5 (High)	31.2 (Low)	+27%

The psychological state of the experimental group also improved significantly, demonstrating a 22% reduction in sports anxiety (29.5 vs. 35.8) and a 32% increase in training satisfaction (91.3% vs. 79.2%). These results indicate a more positive and confident attitude toward training. Furthermore, the experimental group exhibited a 27% higher level of achievement motivation (36.5 vs. 31.2), suggesting an increase in drive and commitment. These findings highlight that multi-ball training not only enhances technical and physical performance but also positively impacts psychological factors, contributing to a more well-rounded and practical training experience.

5. Discussion

Ball familiarity exercises should be integrated with warm-up and cool-down activities, acting as a supplementary practice that students can perform independently after class or during breaks between other technical drills. Encouraging students to practice outside of class is crucial to compensate for limited court time. By maximizing ball utilization efficiency, students can reinforce their training anytime and anywhere, becoming more familiar with the ball's weight, elasticity, spin, and movement characteristics. This will ultimately help them develop a better feel for striking. To ensure practical training, exercises such as bouncing the ball, tapping it with the racket, and toss-and-catch drills should be incorporated. These activities should require students to maintain focus, track the ball closely, and consistently hit the sweet spot, thus promoting ball control and improving hand-eye coordination.

When selecting ball familiarity exercises, it is essential to adhere to the principles of quantity and to customize them to align with students' actual skill levels, ensuring consistent and repetitive practice while gradually increasing the difficulty. This approach is key to developing essential skills such as hand-eye coordination and ball control. During the generalization phase of technical movement learning, students often experience muscle stiffness, uncoordinated movements, and excessive effort. Multi-ball training can effectively address these challenges by providing high-frequency, fixed-ball placement practice that enhances body coordination and reduces muscle stiffness. As students' progress into the refinement and mastery phase, multi-ball training continues to support the development of muscle movement patterns, reinforcing correct motor patterns through frequent repetitions.

Without multi-ball training, students receive inadequate practice in both frequency and intensity, which hinders the development of motor patterns. This issue is particularly pronounced in university tennis elective courses, where large class sizes and limited court space render single-ball training less effective. The experimental results show that students in the experimental group, who engaged in multi-ball training, performed technically correct strokes more effectively within the same time frame compared to the control group. Multi-ball training also allows coaches to provide immediate feedback and make real-time corrections, assisting students in quickly refining their techniques and eliminating common errors. Additionally, coaches can adjust the force, speed, and trajectory of the fed balls to better align with students' progress. This adaptability ensures that training can be customized to meet individual needs, thereby enhancing the overall quality of instruction. Data from the experimental group further validate that multi-ball training significantly enhances technical refinement, resulting in improved stroke success rates and a more efficient learning process, even in large-class environments with limited resources.

6. Conclusion

This study emphasizes the importance of understanding ball behavior—particularly its elasticity, spin, speed, direction, and trajectory—in ball sports. Such understanding is essential for accurate shot positioning and effective racket-ball contact. For amateur tennis players, prioritizing familiarity with the ball during training is crucial, as it enables learners to grasp the fundamental principles of tennis and apply them effectively. This approach not only improves players' foundational skills but should also be widely encouraged in tennis instruction. Moreover, the study confirmed that multi-ball training plays a significant role in enhancing forehand stroke techniques, swing speed, shot accuracy, reaction time, and motor coordination. Multi-ball training is therefore an indispensable component of tennis instruction. Beyond technical execution, it is essential for tennis forehand stroke training to incorporate key concepts such as shot timing, force application, footwork, and strategic awareness, providing a holistic training approach that forms a solid foundation for further skill development.

The following recommendations are proposed to improve the quality of tennis instruction and elevate players' competitive abilities. First, enhancing coaches' professional development is essential. Tennis is a highly technical sport, and coaches need expertise in biomechanics and sports psychology to guide players effectively. Continuous professional development for coaches should be prioritized to ensure they remain current with modern training methodologies. Additionally, enhancing coaching education and training programs, including both higher education and continuing education opportunities, will accelerate the improvement of tennis proficiency among players. Finally, promoting international coaching exchange programs can bring global perspectives into tennis coaching, helping coaches integrate diverse training methodologies and philosophies. By implementing these strategies, tennis instruction will become more accessible, and players' technical skills and competitive performance will be significantly improved.

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References

1. Liang S. Application of multi-ball training in tennis teaching in universities. Frontiers in Educational Research. 2020; 3(9).
2. Wang Z. Application analysis of multi-ball training based on hierarchical teaching method in table tennis teaching and training. In: Proceedings of the 2019 7th International Education, Economics, Social Science, Arts, Sports and Management Engineering Conference (IEESASM 2019).
3. Li C, Hongsaenyatham P. The Effects of Multi-ball Training Program on Badminton Skills of Male Students Aged Between 9-11 Years. International Journal of Sociologies and Anthropologies Science Reviews. 2023; 3(5): 111-118.
4. Gu Y, Yu C, Shao S, et al. Effects of table tennis multi-ball training on dynamic posture control. PeerJ. 2019; 6: e6262. doi: 10.7717/peerj.6262
5. Katsikadelis M, Djokić Z, Lanzoni, IM, et al. Multi-ball training: A review. In: Proceedings Book of the 16th ITTF Sports Science Congress. International Table Tennis Federation, Hungarian Table Tennis Association, University of Pécs; 2021.
6. Fadjri M, Primasoni N, As J. The Effect of Multiball Training on The Target Accuracy of Forehand Strokes and Backhand Drives of Table Tennis Games: Literature Review. Asian Journal of Social and Humanities. 2024; 2(4): 889-895. doi: 10.59888/ajosh.v2i4.231
7. Xie Y. Research on the application of multidimensional training method in college tennis teaching. Frontiers in Sport Research. 2020; 2(3).
8. Zhang S, Chen G, Wu Q, et al. The Interplay Between Table Tennis Skill Development and Sports Performance: A Comprehensive Review. Pacific International Journal. 2023; 6(3): 150-156. doi: 10.55014/pij.v6i3.433
9. Jia Y. Experimental research on the application of fast tennis in universities. Frontiers in Sport Research. 2024; 6(2). doi: 10.25236/fsr.2024.060217
10. Wang Y, Zhang Y. Real time evaluation algorithm of human motion in tennis training robot. Satapathy SC, Agrawal R, García Díaz V, eds. Journal of Intelligent & Fuzzy Systems. 2021; 40(4): 6049-6057. doi: 10.3233/jifs-189444
11. Zhu X, Suo P, Liu F. Similar adaptive responses in the upper body physical performance of table tennis players following the traditional and cluster set resistance and plyometric training. Scientific Reports. 2024; 14(1). doi: 10.1038/s41598-024-78795-4
12. Deng J, Wang Z, Yin M, et al. Energetic and neuromuscular characteristics of table tennis multi-ball practice. Medicine & Science in Sports & Exercise. 2024; 56(10S): 762-763. doi: 10.1249/01.mss.0001059076.81561.50

13. Ma T, Du W, Zhang Q. The Effect of Virtual Reality Technology in Table Tennis Teaching: A Multi-Center Controlled Study. Sensors. 2024; 24(21): 7041. doi: 10.3390/s24217041
14. Wang Y. Rationality evaluation of batting action of table tennis players based on support vector machine model. Revista de Psicología del Deporte (Journal of Sport Psychology). 2021; 30(1): 296-304.
15. Huang J. Effects of Professional Tennis Registry (Ptr) Teaching System on the Mastery of Skills of Tennis Athletes. Journal of Education and Educational Research. 2024; 7(3): 67-74. doi: 10.54097/cc1cg602
16. Lin J, Shao P, Zhang Q. Advancing Tennis Analytics: Comprehensive Modeling for Momentum Identification and Strategic Insights. International Journal of Computer Science and Information Technology. 2024; 2(1): 104-117. doi: 10.62051/ijcsit.v2n1.12
17. Ji J. Edge calculation in tennis movement training. In: Proceedings of the 2023 International Conference on Power, Communication, Computing and Networking Technologies. pp. 1-5.
18. Yan G. Examination on tennis training based on animal bionics. International Journal of Sports Technology. 2021.
19. Mocanu M, Negolescu IC. Optimization of the topspin performance biomechanics in female juniors in table tennis. Discobolul-Physical Education, Sports and Kinetotherapy Journal. 2018; XIV(1),: 50-54.
20. Susetyorini JT, Rahayu T, Rahayu S. Effect of exercise methods and eye-hand coordination on forehand drive table tennis basic technical ability. Journal of Physical Education and Sports. 2019; 8(3).
21. Ke Y, Chano J. Feasibility Study on the Implementation of the Two-Phase Teaching Method of "Short Tennis + Standard Tennis" in General Colleges and Universities. Higher Education Studies. 2024; 14(2): 52. doi: 10.5539/hes.v14n2p52
22. Chen Z. Visual Navigation and Path Planning of Ball Picking Robot based on Swarm Intelligence. In: Proceedings of the 3rd International Conference on Mechatronics Engineering and Information Technology (ICMEIT 2019). doi: 10.2991/icmeit-19.2019.66
23. Feng J. Evaluation and improvement method analysis of college physical education teaching based on modern information technology. In: Proceedings of the 2019 Asia-Pacific Conference on Advance in Education, Learning and Teaching (ACAELT 2019).
24. He J. The application of information technology in the teaching method of table tennis in colleges and universities. In: Proceedings of the 2019 9th International Conference on Education, Management, and Computer (ICEMC 2019).
25. Negulescu I, Mocanu M, Cristea F. Importance of Topspin and Retopspin in Table Tennis for Female Juniors II. The European Proceedings of Social and Behavioural Sciences. 2018; 262-270. doi: 10.15405/epsbs.2018.03.35
26. Zhou Y. Evaluation of Table Tennis Skills Based on Whole Brain Teaching. NeuroQuantology. 2018; 16(5). doi: 10.14704/nq.2018.16.5.1414
27. Wang X. Discussion on the application of level teaching method in table tennis teaching in colleges and universities. In: Proceedings of the 2019 Asia-Pacific Conference on Advance in Education, Learning and Teaching (ACAELT 2019).
28. Ma W, Liu Y, Yi Q, et al. Table tennis coaching system based on a multimodal large language model with a table tennis knowledge base. PLOS ONE. 2025; 20(2): e0317839. doi: 10.1371/journal.pone.0317839
29. Zhang J. Evaluation of the effect of artificial intelligence training equipment in physical training of table tennis players from a biomechanical perspective. Molecular & Cellular Biomechanics. 2024; 21(1): 319. doi: 10.62617/mcb.v21i1.319
30. Yang W, Yin L, Poon ETC, et al. Effects of low-volume court-based sprint interval training on aerobic capacity and sport-specific endurance performance in competitive tennis players. Biology of Sport. Published online 2025. doi: 10.5114/biolsport.2025.139088