Data-Driven Research on the Evaluation and Optimization of Table Tennis-Specific Teaching Effectiveness

Chao Fan
Department of Physical Education, Hebei University of Technology, Tianjin 300400, China
Corresponding author: Chao Fan (e-mail: 16622103112@163.com)

ABSTRACT Table tennis-specific teaching is often constrained by single assessment indicators, delayed feedback, and insufficient individualized guidance, making it difficult to understand students' technical proficiency and training effectiveness accurately. This study develops a data-driven evaluation and optimization model based on multidimensional data collection. Wearable sensors, video analysis, and questionnaires are integrated to collect technical movement data, physiological indicators, and learning feedback from 120 table tennis students. The Analytic Hierarchy Process is used to determine weights for four evaluation dimensions: technical movement, physical fitness, tactical awareness, and theoretical knowledge. K-means clustering then classifies students into four levels—excellent, good, average, and needing improvement—and differentiated training programs are designed accordingly. After a 16-week optimized teaching intervention, serve accuracy in the experimental group increased from 68.3% to 85.7%, while the control group improved only from 68.5% to 74.2%. The model supports objective teaching diagnosis, personalized training, and realtime adjustment, and its sensing architecture is applicable to wireless data transmission and electromagneticcompatible sports monitoring systems.

INDEX TERMS table tennis teaching, data-driven evaluation, personalized training, wireless transmission, wearable sensing

I. INTRODUCTION

As a sport in which China maintains a significant competitive advantage, the quality of table tennis instruction directly influences the cultivation of professional talent and the enhancement of competitive standards. However, contemporary specialized instruction faces a critical dilemma regarding the limitations of traditional assessment methods. The subjective experience that teachers use to assess the technical levels of students does not have quantitative measures, and this results in untimely and inadequately focused teaching feedback. There are considerable individual differences in the students and a standardized training program is hard to fulfill the real needs of learners at various levels. Other students have slow technical gains or sport injuries as a result of inappropriate training intensity. Final exam has traditionally been the basis of the evaluation of the teaching performance, and it is unable to dynamically monitor the learning process and provide teachers with the opportunity to modify the teaching strategy in a timely fashion. All these issues limit the enhancement of the quality of specialized table tennis training and have an urgent need to establish a scientific assessment system and an individual training model [1,2].

The emergence of technologies of data acquisition and analysis has offered new avenues in reform of teaching physical education. The wearable devices will be able to track movement status in real-time, video analysis technology will be able to precisely capture details of the technical movements, and multi-dimensional data fusion will allow the abilities of the students to be assessed comprehensively. In this study, a teaching effectiveness evaluation system is created on the basis of multi-dimensional data acquisition, the weights of evaluation indicators are determined by the analytic hierarchy process (AHP) and clustering algorithms are applied to attain accurate student stratification and develop differentiated training programs. The effectiveness of the data-driven model is checked by comparing experiments and investigates the most optimal ways of personalized teaching. The development of this research should help to offer a scientific foundation of making decisions in table tennis-specific teaching, facilitate the change of teaching assessment by experience-based evaluation to support-based data analysis, and enhance the quality of teaching and the level of competition among students.

II. RELATED WORK

The physical education teaching effectiveness evaluation theory has developed to an evaluation technique based on single indicators to multiple evaluation techniques. Primarily the early assessments involved technical achievement tests and physical fitness tests, and the assessments were based on standardized scales with which the student performance was categorized. Nonetheless, this method overlooked the personal differences and the dynamic learning process [3,4]. The evaluation framework started to be developed in various dimensions, focusing on the development of holistic qualities and was gradually extended to several dimensions: cognition, emotion, and social adaptation after the introduction of the theory of multiple intelligences to the sphere of physical education. Formative assessment concept dictates the inclusion of evaluation in the overall process of teaching, which facilitated development of the student by means of constant evaluation. Evaluation methods have been innovative due to technological developments. Technical diagnosis and training monitoring have used tools like Biomechanical analysis, motion capture system and heart rate monitoring equipment. Other studies have tried to develop models of quantitative evaluation, which integrate subjective evaluation with objective measurement, but controversies on the weighting of indicators and standardizing the evaluation criteria remain. Analytic hierarchy process (AHP) has been used in the evaluation of education as a decision making tool of multi criteria. It is able to deal with complex evaluation systems and measure the experience of experts and offer methodological backing to scientific distribution of indicator weights. Table tennis-specific teaching research is concerned with the novelty of the instructional approaches and models of technical and tactical training. Technical training is based on standardization of movements and progressive training that teaches students to develop proper forms of movement by using a mix of decomposed practice and general training. Tactical training focuses on simulating matches and the development of flexibility, but does not provide a systematic evaluation of the tactical level of thinking of students. The idea of personalized teaching is slowly finding its way into table tennis teaching, with some applied investigations grouping students by technical level; but grouping is frequently a matter of subjective judgment on the part of teachers and the rigor and accuracy of the grouping method requires enhancement. Data analysis technology has been primarily applied in training table tennis in professional sports teams where high-speed photography and tracking of trajectories are used to examine technical aspects, yet in typical teaching practice there is little use of data analysis technology [5,6]. The student classification demonstrated by clustering algorithms has a promising future to determine group patterns using multi-dimensional features with automatic identification of group patterns, an objective basis of differentiated teaching. The literature has not provided a systematic solution that is based on the combination of multi-source data collection, scientific evaluation modeling, and individual program design; this paper investigates this gap.

III. METHODS

A. DESIGN OF MULTIDIMENSIONAL DATA ACQUISITION SYSTEM

The data collection subjects were chosen as 120 students who major in table tennis in a college of sports and a data collection system was installed that had three dimensions: technical movements, physiological indicators, and subjective feedback. High-speed cameras at the four corners of the table were used to record the technical movement data at a collection frequency of 240 frames per second and this recorded the entire sequence of the movement of 12 basic techniques, which included serving, receiving, and forehand and backhand attack. The extracted joint coordinates were utilized to determine the kinematic parameters of the elbow joint angle, the amplitude of waist rotation and the center of gravity movement trajectory at the impact point through the OpenPose posture recognition algorithm [7,8]. Physiological measurements were recorded with the help of a wearable heart rate monitor and an accelerator that captured the change curve of the heart rate and the distribution of the intensity of the exercise and energy usage data in real time during training. The sensor sampling rate was 100 Hz with the data being transferred to the central processing unit through Bluetooth. The electronic questionnaire with four modules of the self-assessment of technical mastery, perception of training load, interest in learning, and recognition of difficulties was used to obtain subjective feedback data. The questionnaire used a five-point Likert scale and was filled out every two weeks. All data were stored in a unified MySQL database, and an index was established to associate student IDs with data records for easy retrieval in subsequent analysis. This study was approved by the Ethics Committee of Hebei University of Technology, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

B. CONSTRUCTION OF AN EVALUATION INDEX SYSTEM BASED ON AHP

Eight national-level coaches of table tennis and five sports education experts were invited to form an evaluation team to develop a judgment matrix to calculate the weights of each evaluation dimension. The four main indicators that were evaluated by the evaluation team on a pairwise basis and assessed using the scale of 1-9 to determine their importance included technical movements, physical fitness, tactical awareness and theoretical knowledge. The technical movement dimension consisted of five secondary indicators, namely: serve quality, forehand attack, backhand push, footwork and hitting rhythm. There were four indicators of physical fitness: endurance, explosive power, flexibility, and reaction speed. Two indicators within tactical awareness included: application of match strategies and adaptability. Theoretical knowledge entailed two pointers: rule learning and technical and tactical cognition [9,10]. The geometric mean was performed with the help of the 13 obtained experts and the weighting of the technical movements was 0.45, physical fitness 0.30, tactical awareness 0.15 and theoretical knowledge 0.10. The judgment matrix was also tested to be consistent and the consistency ratio (CR) was determined to be 0.078, which is lower than the standard of 0.1, which shows that the weight distribution was sensible. Multiply the weight of the secondary indicators with the weight of the respective primary indicators to come up with the weight of the 13 secondary indicators to make a complete hierarchical system of evaluation indicators to measure the overall level of performance among students.

C. K-MEANS CLUSTERING HIERARCHICAL MODEL

A sample matrix was constructed with the evaluation data of 120 students on 13 secondary indicators with each student in the sample being represented by a row vector in the sample matrix. The Z-score normalization was applied to normalize the raw data because of the great differences in the size of each indicator, which removed the effect of the numerical range on the results of the clustering. The optimal number of clusters was determined using the Elbow Method and Silhouette Coefficient analysis. The results indicated that K=4 provided the most distinct separation and internal consistency among the data points, which naturally aligns with four proficiency levels: excellent, good, average, and requiring improvement. The initializing of the cluster centers was done through the K-means++ algorithm, which prevents the local optima due to random selection. In the iteration process, Euclidean distance between each sample of the students and the four cluster centers was calculated and the sample was classified as belonging to the closest cluster. The centroid values of both clusters were again recalculated and the positions of the clusters centers were changed. The highest number of iterations was established to be 300. Calculating was stopped when the difference between all cluster centers was less than 0.001 on two successive iterations or when the number of iterations was exceeded. The silhouette coefficient was also computed after clustering to determine the quality of stratification of the clusters giving a value of 0.63, which suggests that clusters are dense and that there is a clear separation between clusters. The distribution of people at each level was statistically analyzed: 18 people in the excellent level, 35 people in the good level, 42 people in the average level, and 25 people in the level that needs improvement. This presents a reasonable pyramid structure and verifies the effectiveness of the stratification model.

D. DESIGN OF DIFFERENTIATED TEACHING OPTIMIZATION SCHEME

According to the clustering findings, a 16-week training schedule has been put together considering that students at four levels will be trained, and there will be six classes in a week with each taking 90 minutes. In more advanced students, the emphasis is placed on more difficult tactical combinations such as multiball continuous attacks and swings of varying speed. The prescribed training load is calibrated to target a physiological response of 160-180 beats per minute for advanced students, utilizing a ball machine to receive the fast returns at 80 balls per minute. Match simulations comprise 40% of the total training time. In the case of good students, it involves enhancement of technical stability, 300 hits every set during the fixed-point multiball training and the heart rate of 140-160 beats per minute. The deviation in the wrist angle is corrected by coaches during demonstration in slow motion at the point of impact. The match training takes 30% of training time. In the case of intermediate students, the accent is on the solidification of fundamentals, the technique breakdowns on each side, focusing on 150-200 high-quality repetitions aimed at technical consistency. This volume allows for adequate recovery and integration with match-play training within the 90-minute session. In serving practice, both the landing point error and physical conditioning have to be specified to ensure the error is kept within one-third of the table area, in combination with a certain physical conditioning to enhance movement speed. Match training is 20% of the training time. More advanced students will be provided with practical instructions, and coaches will help them to accomplish 200 swing paths. They will train on their own with the ball bouncing on the wall and simple tactical exercises will be provided to make the learning process easier. For students with lower foundations, the exercise intensity is controlled to maintain a target heart rate zone of 120-140 beats per minute to ensure safety and fundamental skill acquisition, while theoretical classes will be doubled to two times a week to demonstrate the main aspect of techniques.

IV. RESULTS AND DISCUSSION

A. DATA ACQUISITION AND PROCESSING RESULTS

This research gathered baseline data on 120 students in the period between September 2025 and January 2026, and received 14,400 video clips of technical movements, 86,400 records of physiological indicators monitoring, and 960 questionnaire feedback data. In data preprocessing, 273 invalid data records (resulting from equipment malfunction or partial student absence during specific sessions) were eliminated and a valid dataset of 101,587 data points was obtained. 13 secondary indicators were statistically analyzed, finding the mean and standard deviation of each indicator. The results are shown in Table 1. Data analysis shows that there exist considerable differences between students in the technical movement dimension and standard deviation in serve quality score is 12.8, which means that there is uneven mastery of serve techniques. Explosive power had the lowest mean score of 62.3 points as compared to other indicators in the physical fitness dimension which means they lacked strength training. The general score of the tactical awareness dimension was low with the mean score of 55.7 points of game strategy application and 58.4 points of adaptability, which reflects that there is no practical experience among students. Theoretical knowledge scores were fairly focused and high, standard deviations of 8.2 and 9.1 on rule comprehension and tactical awareness respectively, indicating a fairly equal influence of theoretical instruction. The stratification and classification of students were done based on these data using a K-means clustering model.

TABLE 1. Statistical Results of Student Baseline Data

Evaluation Dimensions	Secondary indicators	mean	Standard deviation
Technical movements	Serve quality	68.5	12.8
Technical movements	Forehand attack	71.2	11.6
Technical movements	Backhand push	65.8	13.4
Technical movements	Footwork	69.3	10.9
Technical movements	Rhythm of the ball	66.7	12.1
Physical fitness	endurance	70.4	9.8
Physical fitness	explosive force	62.3	11.5
Physical fitness	flexibility	68.9	10.2
Physical fitness	reaction rate	66.1	11.8
Tactical awareness	Application of game strategies	55.7	14.3
Tactical awareness	Adaptability	58.4	13.7
Theoretical knowledge	Rule understanding	75.6	8.2
Theoretical knowledge	Technical and tactical understanding	73.2	9.1

B. ANALYSIS OF THE EFFECTS OF TEACHING OPTIMIZATION

In this study, the 120 students were divided into experimental (n=60) and control (n=60) groups using stratified random sampling based on their initial clustering results. This ensured that the distribution of skill levels was statistically identical in both groups to allow for a fair comparison between the differentiated optimization program and the traditional teaching model. Experimental group was provided with teaching optimization program that was differentiated, and the control group was provided with the traditional teaching model. Both the groups were trained over 16 weeks. All students were subjected to the technical and physical fitness tests after the training. Thirteen secondary indicators (the same as the baseline data) were measured, and the data of both groups was subjected to a paired samples t-test with a level of significance of 0.01. Table 2 presents the results of comparison of pre- and post-test data in the experimental and control groups.

TABLE 2. Comparison of teaching effects between experimental and control groups

Evaluation Dimensions	Secondary indicators	Pre-test of experimental group	Post-test of experimental group	Pre-test of control group	Post-test of control group	p-value
Technical movements	Serve accuracy (%)	68.3	85.7	68.5	74.2	<0.01
Technical movements	Forehand attack success rate (%)	71.2	88.4	71.0	78.6	<0.01
Technical movements	Backhand push to score	65.8	83.2	65.6	72.4	<0.01
Technical movements	Footwork movement scoring	69.3	84.6	69.5	75.8	<0.01
Technical movements	Score points based on hitting rhythm	66.7	82.1	66.9	73.3	<0.01
Physical fitness	Overall score improvement (%)	-	23.6	-	9.8	<0.01
Tactical awareness	Application of game strategies	55.7	76.3	55.9	62.4	<0.01
Tactical awareness	adaptability	58.4	78.9	58.2	64.7	<0.01

The experimental group's serving accuracy improved from 68.3% to 85.7%, an increase of 17.4 percentage points, while the control group's improvement was only 5.7 percentage points, from 68.5% to 74.2%. The forehand attack success rate increased from 71.2% to 88.4% in the experimental group, an increase of 17.2 percentage points, while the control group's increased from 71.0% to 78.6%, an increase of 7.6 percentage points. The overall physical fitness test score improved by 23.6% in the experimental group and by 9.8% in the control group. Statistical tests showed that the experimental group's improvements in all indicators were significantly better than the control group's, with p-values all less than 0.01, demonstrating the significant effect of the differentiated teaching program. The most significant improvement was seen in the tactical awareness dimension, with the experimental group's score in game strategy application increasing from 55.7 to 76.3 and adaptability increasing from 58.4 to 78.9, indicating that personalized training effectively enhanced students' practical skills.

C. PROGRESS OF STUDENTS AT DIFFERENT LEVELS

This study statistically analyzed the training effects of 60 students in the experimental group according to the clustering results. The mean development of the students in four levels (excellent, good, average, and needing improvement) on 13 indicators at the secondary level was computed and compared with the baseline data of the four levels. Figure 1 illustrates the particular development of the students at various levels.

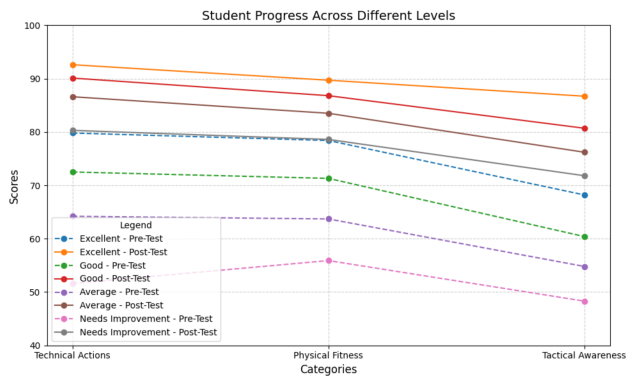

FIGURE 1. Progress of students at different levels

Students at the "Need for Improvement" level showed the most significant progress, with their technical movement score increasing from a baseline of 51.6 to 80.3. Specifically, their serve quality improved from 49.2 to 79.8, and their forehand attack from 52.3 to 81.9, indicating that targeted, hands-on guidance and simplified training effectively addressed the technical weaknesses of students with weak foundations. Intermediate-level students saw their technical movement score improve from 64.2 to 86.6, and their physical fitness score from 63.7 to 83.5, demonstrating that fundamental skills consolidation training significantly enhanced their movement stability. Good-level students improved their technical movement score from 72.5 to 90.1, and their tactical awareness from 60.4 to 80.7, indicating that high-intensity technical and tactical combination training improved their actual combat level. The technical skills of students at the excellent level improved from 79.8 points to 92.6 points. Although the absolute improvement was small, their average score in the subsequent test reached 92.6 points, which is close to the technical limit. Their tactical awareness improved from 68.2 points to 86.7 points. The competition simulation training enhanced their competitive ability and verified that the differentiated program had a positive effect on students at all levels.

V. CONCLUSION

In this research, the evaluation system of table tennis-specific teaching effectiveness was created on the basis of multidimensional data collection, which would eliminate the problems of individual evaluation indicators and the lack of personalised guidance. Using the analytic hierarchy process (AHP) a scientific weight allocation mechanism was developed and K-means clustering was utilized to accomplish an accurate student stratification giving an objective foundation of creating differentiated teaching plans. The experimental outcomes confirmed that the substantial benefits of the data-driven model are to enhance technical mastery, to increase the level of physical fitness, and to develop a sense of tactics, proving that this approach can effectively enhance the quality of teaching. The study offers a working technical direction and empirical validation of the sports-specific teaching reform, which has a great deal of application potential. Further studies can be extended to other ball sports to investigate more correlation mechanisms between physiological indicators and technical performance, enhance the intelligent teaching assessment system, and enhance the progress of physical education towards precision and tailor-made.

AUTHOR CONTRIBUTIONS

Chao Fan designed, collected and analyzed the data, and drafted the manuscript. Chao Fan conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Chao Fan 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.

FUNDING

This research received no external funding.

HUMAN RESEARCH SUBJECTS

This study was approved by the Ethics Committee of Hebei University of Technology, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

ACKNOWLEDGEMENTS

Not applicable.

REFERENCES

[1] H. Sheng, "Application of Hierarchical Teaching in Table Tennis Teaching in Colleges," Clausius Scientific Press, 2021, doi: 10.23977/JHMS.2021.020406.

[2] S. Siregar, R. Hasibuan, and M. Y. Ahady, "Development of Digital-based Table Tennis Teaching Materials," Proceedings of the 5th International Conference on Innovation in Education, Science, and Culture, ICIESC 2023, 24 October 2023, Medan, Indonesia, 2024, doi: 10.4108/eai.24-10-2023.2342055.

[3] H. Pinggui, "Teaching of Backspin Serve in Table Tennis," Journal of Education and Culture Studies, 2022, doi: 10.22158/jecs.v6n2p115.

[4] R. Qi and R. Li, "Network Multimedia Table Tennis Teaching Design Based on Embedded Microprocessor," Wireless Communications and Mobile Computing, 2022, doi: 10.1155/2022/2019857.

[5] H. Y. Ren and D. Wang, "Optimization Algorithm of College Table Tennis Teaching Quality Based on Big Data," 2021, doi: 10.23977/AETP.2021.54023.

[6] W. Zeng, "Table Tennis Teaching 3D Model Based on Hierarchical Clustering Intelligent Algorithm," First International Conference on Real Time Intelligent Systems. Springer, Cham, 2024, doi: 10.1007/978-3-031-55848-1_34.

[7] I. Ivanov, A. Petrova, Z. Nikolova, et al., "DEVELOPMENT OF THE PHYSICAL QUALITY OF AGILITY THROUGH THE SPORT OF TABLE TENNIS (REVIEW)," Knowledge: International Journal, vol. 74, no. 4, 2026.

[8] Y. Wang and P. Sup, "Exploration of Physical Fitness Training Path in Table Tennis Teaching in Middle School," Frontiers in Sport Research, 2021, doi: 10.25236/FSR.2021.030207.

[9] M. N. Ortega-Zayas, A. J. Cardona-Linares, A. Quílez, et al., "Development and validation of a questionnaire for table tennis teaching in physical education," FRONTIERS IN PSYCHOLOGY, vol. 16, Art. no. 1550061, 2025, doi: 10.3389/fpsyg.2025.1550061.

[10] I. B. Endrawan, H. Nufus, B. Hermansah, et al., "Effectiveness of plyometric training programme in increasing reaction speed in table tennis game," Fizjoterapia Polska, no. 1, 2025, doi: 10.56984/8ZG007DV66X.