Technical and Tactical Diagnosis Model of Table Tennis Matches Based on BP Neural Network

Wenwen Huang

Shanghai University of Sport

Miaomiao Lu

Shanghai University of Sport

Yuxuan Zeng

Shanghai University of Sport

Mengyue Hu

Shanghai University of Sport

Yi Xiao (✉ cutexxx@163.com)

Shanghai University of Sport

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Technical and Tactical Diagnosis Model of Table Tennis Matches Based on BP Neural Network

Running title: Technical and Tactical Diagnosis Model of Table Tennis

Wenwen Huang¹, Miaomiao Lu², Yuxuan Zeng¹, Mengyue Hu², Yi Xiao^{*1}

¹China Table Tennis College, Shanghai University of Sport, Shanghai, China

²School of Economics and Management, Shanghai University of Sport, Shanghai, China.

*Corresponding author: Yi Xiao, China Table Tennis College, Shanghai University of Sport, 200438, Shanghai, China, E-mail: cutexxx@163.com.

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Competing interests

The authors declare that they have no competing interests.

Abstract

Background: The technical and tactical diagnosis of table tennis is extremely important for the preparation of matches, and there is a nonlinear relationship between athletes' performance and their sports quality. As the neural network model has high nonlinear dynamic processing ability and has high fitting accuracy, the main purpose of this study was to establish a technical and tactical diagnosis model of table tennis matches based on a neural network to diagnose the influence of athletes' techniques and tactics on the competition result.

Methods: A three-layer back propagation neural network model for table tennis match diagnosis were established. The 30 technical and tactical analysis indexes that are closely related to winning a competition were selected based on the double three-phase evaluation method. And 100 table tennis matches were selected as data sample, of which 70 matches were taken as training sample to establish the diagnostic model, the other 30 matches were used to test the validity of the diagnostic model.

Results: The technical and tactical diagnosis model of table tennis matches based on BP neural network had a high precision up to 99.997% and highly efficient in fitting ($R^2 = 0.99$). It had a good ability to diagnose the technical and tactical abilities of table tennis players. The technical and tactical diagnosis results showed that the scoring rate of the fourth stroke of Harimoto had the greatest influence on the winning probability.

Conclusion: The technical and tactical diagnosis model of table tennis matches based on BP neural network had a high precision and highly efficient in fitting. By using this model, the weights of the influence of athletes' technical and tactical indexes on the

43 winning probability of the competition can be calculated, which provides a valuable
44 reference for formulating targeted training plans for players.

45 **Key words:** artificial neural network; table tennis; techniques and tactics; diagnostic
46 model; winning probability

47

Background

Compared with physical events (such as track and field, cycling, swimming, etc.), one of the most important characteristics of ball games is that there is a nonlinear relationship between athletes' performance and their sports quality [1]. Sports games were classified into five levels according to their technical and tactical importance, and ball games were the highest one [2]. The successful use of techniques and tactics is the decisive factor in the game outcome. Therefore, the technical and tactical diagnosis of ball games is extremely important not only for the preparation of matches but also for future training.

As a net ball game, table tennis has the characteristics of many variations, fast ball speed and rotation speed, which requires a high skill level for table tennis players. The result of table tennis competition is affected by multiple factors, such as physical fitness, psychology, techniques, tactics, and so on, among which the techniques and tactics is the core one, which has a direct effect on the result of the competition [3]. The technical and tactical diagnosis of table tennis competitions can not only provide useful guidance for training but also improve the competitive ability of athletes [4, 5]. Therefore, the systematic analysis and diagnosis of the players' technical and tactical characteristics are very important and crucial in preparing for table tennis competitions [6, 7].

With regard to the technical and tactical diagnosis method of table tennis, the most classical one is the three-phase evaluation method which was put forward by Wu [8]. It takes a player's last stroke in each rally as the observation unit and divides each rally into three phases: attack after service (the first and third strokes), attack after receive

(the second and fourth strokes), and stalemate phase (after the fourth strokes). The scoring rate (SR) and the usage rate (UR) are used as evaluation indexes for analysis. This method has been widely used in many researches to evaluate the strength of table tennis players' techniques and tactics, and China's table tennis team conducts a technical and tactical analysis for their own players and major opponents during the preparation in every world championship and Olympic Games [7, 9-11].

According to the time sequence characteristics of each game, a table tennis game can be divided into three stages: the beginning, the middle, and the end. Combining the division of the three-phase evaluation method and the division of a game, the double three-phase evaluation method was proposed by Xiao, et al., which still uses the SR and UR in the beginning, the middle, and the end of each game to evaluate the strength of players' technic and tactic performance [12].

Using the double three-phase evaluation method, the competition can be analyzed from two different perspectives to make the results more specific. If analyzing from the perspective of game division (the beginning, the middle, and the end), the variation of players' technical and tactical use in the competition can be observed. If analyzing from the perspective of three-phase evaluation, the performance of players' techniques and tactics in the competition can also be found [12]. The double three-phase evaluation method can make a more comprehensive analysis of the variation and strength of players' techniques and tactics in the competition, which is a useful supplement to the three-phase evaluation method.

With the development of information technology, there are a variety of diagnosis

and analysis methods for a sports game, such as the multiple regression analysis, the Markov chain, the Artificial Neural Network (ANN), and so on [7]. However, as the competition result of table tennis is affected by many factors, and the relationship between the competition result and players' technical and tactical ability is mainly nonlinear, it's hard to determine the impact of athletes' technical and tactical performance on the competition result by applying the linear or similar to linear analysis methods.

Multiple regression analysis model can be used to diagnose the relationship between sports competition performance and a series of influencing factors [13]. The advantage of a multiple regression model is that it can better reveal the impact of each independent variable on the dependent variable. However, the multiple regression analysis model is a static process, and the table tennis match is dynamic, therefore, it is a little lopsided to the technical and tactical diagnosis of table tennis matches [14].

The Markov Chain Model can simulate the winning probability of a table tennis match. When one of the indexes affecting the win of a match changes, the model can diagnose the winning probability of a match again. Hence, researchers can determine what influence a change in one index value (increasing or decreasing) will have on the output (winning probability) by comparing the difference of winning probability. Pfeiffer et al. proposed four different state transition models to describe the tactical behavior of table tennis by using the Markov chain, and the results demonstrated that the random path simulation of the Markov chain was valuable in the technical and tactical diagnosis of table tennis matches [15]. Newton used the stochastic Markov

chain model to propose the probability density function of players' winning in tennis matches, and the results showed that the Markov chain could provide more detailed information for the diagnosis of players' athletic ability and the winning probability of tennis matches [7, 16].

An artificial neural network (ANN) is a complex network system that carries out parallel processing and nonlinear transformation of information by simulating human brain neural processing. Compared with traditional multiple regression, ANN has a high nonlinear dynamic processing ability [17]. The basic idea of a neural network model is quite similar to that of the Markov chain model. The main difference between them is that the Markov chain model requires the integrity of data structure and its time sequence, however, the neural network model has no strict requirement for input indexes [7]. When the input and output relationship is too complicated to be expressed by general formulas, it is easy for neural networks to realize their highly nonlinear mapping relationship. The learning process of a neural network is essentially a process of optimizing the weights of the neural network, which often requires hundreds of iterative operations. Hence, choosing a reasonable neural network structure can reduce network training times and improve the training accuracy of the model. ANN has been widely used in the fields of pattern recognition, automatic control, and economic diagnosis, etc. [18-21].

Back propagation (BP) neural network is a neural network learning algorithm proposed [22]. It is a multi-layered feedforward neural network trained by backward error propagation. It takes squared error as its objective function and calculates the

minimum of the error function by gradient descent method [7]. The basic structure of a three-layer BP neural network includes three parts: an input layer, hidden layer, and output layer. The key to establishing a three-layer BP network model is the determination of the input layer's neuron number, the hidden layer's number, the hidden layer's neuron number, the selection of transferring function as well as the training function. The high nonlinear processing ability of BP neural network makes it widely applied in game prediction, and technique and tactics diagnosis for ball matches [13, 23, 24]. Yang & Zhang used BP neural network and multiple regression to analyze the technical and tactical ability of excellent male table tennis players, and the results showed that the overall fitting accuracy of the BP neural network was higher than that of the multiple regression model [13].

As the neural network model has no strict requirement for input indexes and has high fitting accuracy, in this study, the BP neural network was used to establish a technical and tactical diagnosis model of table tennis matches. The main idea is to develop a computational model that can simulate the winning probability of a table tennis match. When one of the technical and tactical index's value is adjusted, the winning probability of the match can be recalculated through the diagnostic model in order to examine the impact of that index on the winning probability, which provides an effective way for the technical and tactical diagnosis of table tennis matches. At the same time, the diagnostic model was applied to analyze the technical and tactical diagnosis of the world's elite table tennis player, so as to provide a valuable reference for formulating targeted training plans and improving players' winning probability.

Methods

Double three-phase evaluation method

Three-phase evaluation method

The three-phase evaluation method of table tennis technique and tactic divides each rally into three phases: the serve and attack phase, the receive and attack phase, and the stalemate phase. It uses the scoring rate (SR) and the usage rate (UR) in each phase of each game to analyze the strength of table tennis players' techniques [7]. The definition of SR and UR are as follows [4]:

$$\text{Usage Rate: } UR_i = \frac{W_i + L_i}{S}$$

$$\text{Scoring Rate: } SR_i = \frac{W_i + L_i}{S}$$

where i is the number of each phase, UR_i is the usage rate at the i -th phase, SR_i is the scoring rate at the i -th phase, W_i is the scoring points at the i -th phase, and L_i is the losing points at the i -th phase, and S is the total points of both sides scored during a match.

Division of a game

According to the time sequence characteristics of each game, a table tennis game can be divided into three stages: the beginning, the middle, and the end, which are defined as follows:

(1) the beginning of a game: before the score of either side reaches 5 points (first to fourth points); (2) the middle of a game: from the score of either side reaches 5 points to 8 points (fifth to eighth points); (3) the end of a game: from the score of either side reaches 9 points to the end of a game.

The structure of double three-phase

Combining the three-phase evaluation method and the division of a game, Xiao, et al. put forward the double three-phase evaluation method, which still uses the SR and UR in the beginning, middle, and the end of each game to evaluate the strength of players' technic and tactic performance [12].

The analysis indexes based on the double three-phase evaluation method

In this study, the 30 technical and tactical analysis indexes which have a closer relation to winning a competition were selected based on the double three-phase evaluation method, including three kinds of scoring rate and usage rate, which were illustrated in Table 1.

Table 1 The thirty technical and tactical analysis indexes based on the double three-phase evaluation method.

In this paper, the player's competition result of a match is described by the winning probability, which is defined as the total winning points of one side divided by the total scores of both sides in a match [6].

Neural network diagnostic model

Neural network structure

In this paper, 100 matches of the world's elite male table tennis players were selected, and the technical and tactical analysis of these matches was conducted by our research team using the double three-phase evaluation method. The results of the technical and tactical analysis, including the thirty technical and tactical analysis indexes and the winning probability, were used as the data sample and a three-layer BP

neural network model for table tennis match diagnosis was established by adopting the Levenberg-arquardt training function.

The input layer of the diagnostic model included 30 neurons which correspond to 30 technical and tactical analysis indices (from x_1 to x_{30}), respectively. The output layer of the diagnostic model was the winning probability of a table tennis match, and the hidden layer included 31 neurons. The number of the hidden layer's neurons can be changed according to the requirement of the model's precision. The nonlinear S transferring function (activation function) $\text{tansig}(n)$ was taken between the input layer's neurons and the hidden layer's neurons, and the linear transferring function $\text{purelin}(n)$, i.e. $f(x)=x$, between the hidden layer's neurons and the output layer's neurons was taken, whose structure was shown in Figure 1 [25].

Fig 1. Neural network model structure

Neural network training

The 100 matches were divided into two groups, of which 70 matches were taken as neural network training samples to establish the diagnostic model of table tennis matches, the other 30 matches were used to test the validity of the diagnostic model.

The BP self-learning algorithm was used to learn the training samples. After learning, the winning probability (the output data) of the table tennis diagnostic model can be obtained. Then, the input and output data of the diagnostic model can reflect the functional relationship between the technical and tactical indicators (input layer) and the winning probability (output layer) of the matches. In order to make the diagnostic model have faster convergence speed and higher stability, the Levenberg-Marquardt

training function was adopted in this paper. The Levenberg-Marquardt training rule has the characteristics of fast calculation speed and high precision, whose specific steps are as follows [25]:

Step-1: Setting initial weight W ;

Step-2: For the input indices ($X_1, X_2, \dots, X_{30}$) of all training samples: (1) Calculating the output of hidden neurons: $H_j = f(\sum W_{ji} X_i - \theta_j)$ ($i = 1$ to 30 ; $j = 1$ to 31), where W_{ji} is the connection weight between neuron i and j , θ_j is the j -th hidden neuron's threshold value; (2) Calculating the output of the output neuron: $y = f(\sum W_j H_j - \theta_o)$ ($j = 1$ to 31), where W_j is the connection weight between neuron j and output neuron, θ_o is the output neuron's threshold value; (3) Calculating the mean squared error of all sample's actual and expected output: $e = \sum (t - y)^2 / 2$, where y is the actual output value, and t is the expected output value.

Step-3: Anti-propagation computing weight correction vector: $\Delta w = [J^T J + uI]^{-1} J^T e$;
Correcting all net weights: $w_{k+1} = w_k + \Delta w$, where k is training steps, J is Jacobian matrix derived by the partial derivative of the error to weight, I is a unit matrix, e is network error vector, and u is the increasing coefficient (a scalar). When the error has not reached the expected value, u is reduced, otherwise, u is increased.

Step-4: Repeating Step-2 and Step-3 until one of the following conditions is met: the error meets the requirements or the training step exceeds the given value.

Neural network programming

The learning process of a neural network is essentially a process of optimizing the weights of the neural network, which requires hundreds of iterative operations, so the

amount of calculation in the learning process of the neural network is quite large and needs to be realized by programming. The neural network development kit of Matlab R2016b was utilized to develop the diagnostic model's program, which was as follows.

The input data matrix p and output data matrix t of the training sample are input into the diagnostic model.

```
p = zeros (30, 70);
```

```
p = xlsread ('sample.xls');
```

```
p = p';
```

```
t = zeros (1, 70);
```

```
t = xlsread ('output.xls');
```

```
t = t';
```

```
net = newff (minmax(p), [31,1], {'tansig', 'purelin'}, 'trainlm');
```

```
net.trainParam.show = 5;
```

```
net.trainParam.epoch = 300;
```

```
net.trainParam.goal = 1e-5;
```

$[net, tr] = \text{train}(net, p, t)$; Note: The training parameter show is the times of each training before displaying the training result, epoch is the number of training times, and goal is the training error range between the output and actual value of the model.

Training time and error

The training time and error precision of the table tennis diagnostic model were shown in figure 2. The x-axis is the training times (epoch), the y-axis is the training error. The training precision of the diagnostic model was set $1e-5$. As shown in figure

2, when the training time reached 6, the model's training precision ($1.03e-7$) reached and exceeded the precision requirement set by the program ($1e-5$), which indicated the diagnostic model's precision was high.

Fig 2. Training time and error precision

Training result analysis

After training and learning, the SIM function (program code: $t_sim = sim(net, p_test)$) was used to simulate the output of the model, and compare the output data (Y) with the targeted output (T) to verify the performance of the diagnostic model. The result was shown in figure 3, in which the small white circle represented the output of the neural network diagnostic model, the blue dotted line represented the ideal regression line ($Y = T$), and the red solid line represented the best regression line. The blue dotted line and the red straight line almost overlapped, and the output data points of the neural network diagnostic model were all close to the ideal regression line, indicating that the network had a very good performance and high fitting precision.

Fig 3. Training result analysis

The precision of the diagnostic model

The 30 indexes data of the other 30 matches were input as test samples into the neural network diagnostic model of table tennis matches, and the simulated values of the winning probability of these matches were obtained. These values were used to examine the model's precision, and the results were shown in Table 2 and Figure 4.

Table 2 The error between actual and simulated values

The data of table 2 showed that the maximum absolute error of the 30 matches

was about 0.0016, while the minimum error was about 0.000006, the average error of the 30 matches was 0.0004. As shown in Figure 4, the winning probability derived from the BP neural network diagnostic model of table tennis match was very close to the actual value, which showed that the diagnostic model based on BP neural network reached a high precision up to 99.997%, and the model analyzing the technical and tactical abilities of table tennis players based on the BP neural network was highly efficient in fitting ($R^2 = 0.99$) [13].

Fig. 4 Accuracy of the diagnostic model

Application of the diagnostic model in table tennis diagnostic analysis

The calculation of the weight of technical and tactical indexes on winning probability

In this study, the impact of technical and tactical indexes on the winning probability was examined by adjusting the value of each technical and tactical index, while keeping the other indexes' value unchanged, and recalculating the winning probability of the match through the diagnostic model [7].

The calculation of the weight of each technical and tactical index's impact on the winning probability is as follows:

(1) Inputting the unchanged data matrix into the neural network diagnostic model to training, and calculating the winning probability (wp1) of the matches.

(2) According to the formula (1), adjusting the value of the selected technical and tactical index, and keep the others unchanged.

$y = 0.238 * \cos(-1.32 * x + 0.66) - 0.178$ (1) [26], where x is the unchanged value of the selected index, and y is the adjusted increment.

(3) Inputting the changed data matrix into the neural network diagnostic model to training again, and recalculating the winning probability (wp2) of the matches.

(4) Calculating of the weight of selected technical and tactical index on the winning probability: $\text{weight} = (\text{wp2} - \text{wp1}) / \text{wp1} * 100\%$. The larger the absolute weight value is, the higher the influence of the selected index on the winning probability.

Example of the technical and tactical diagnosis analysis based on BP neural network model

In this paper, the Japanese famous table tennis player, Harimoto, was taken as an example. 20 international competitions that Harimoto participated in in the past five years (from 2015-2019) and the technical and tactical analysis of the 20 matches was conducted using the double three-phase evaluation method. Then, the thirty technical and tactical analysis indexes were input into the neural network diagnostic model for training and the outcome (winning probability) of the matches was obtained. The weights of thirty technical and tactical indexes' impact on the winning probability were also calculated by adjusting the value of each technical and tactical index one by one according to the formula (1) and keep the others unchanged (repeat thirty times in total).

The results of the technical and tactical diagnosis analysis based on BP neural network model were shown in Figure 5.

Fig 5. The technical and tactical diagnostic results of Harimoto

The perspective of game division (the beginning, the middle, and the end)

At the beginning of the game, the weight of X20 was the largest, indicating that the SR of the fourth stroke had the greatest influence on the winning

probability, followed by X2, X8, and X14, which showed that the SR of the serve, receive, and the third stroke had a greater influence on the winning probability. The two technical and tactical indicators X13 and X19 had a certain impact on the winning probability. The indicators X1, X7, X25, and X26 had little effect on the winning probability.

In the middle of the game, the weight of X22 was the largest, indicating that the SR of the fourth stroke had the greatest impact on the winning probability, followed by X4, X10, and X16, which showed that these three indicators had a greater influence on the winning probability. The two technical and tactical indicators X15 and X21 had a certain impact on the winning probability. The indicators X3, X9, X27, and X28 had little effect on the probability of winning.

At the end of the game, the weight of X24 was the largest, indicating that the SR of the fourth stroke had the largest influence on the winning probability, followed by X6 and X18, which showed that the SR of serve and the third stroke had a greater influence on the winning probability. The three technical and tactical indexes X12, X17, and X23 had a certain influence on the winning probability. The indicators X5, X11, X29, and X30 had little impact on the winning probability.

The perspective of the division of the three-phase evaluation method

At the serve and attack phase, the weight values of X2 and X14 were large, indicating that the SR of the serve and the third stroke at the beginning of the game had the greatest influence on the winning probability, followed by X4, X6, X16, and X18, which showed that these four technical and tactical indicators had a greater impact on

the probability of winning. The indicators X13, X15, and X17 had a certain influence on the winning probability. The indicators of X1, X3, and X5 had little effect on the winning probability.

At the receive and attack phase, the weight of X20 was the largest, indicating that the SR of the fourth stroke at the beginning of the game had the greatest influence on the winning probability, followed by X22 and X24, which showed that the SR of the fourth stroke in the middle and at the end of the game had a greater influence on the winning probability. The indicators X8, X10, X12, X19, X21, and X23 had a certain influence on the winning probability. The indicators X1, X9, and X11 had little effect on the winning probability.

At the stalemate phase, all the indicators X25, X26, X27, X28, X29, and X30 had little effect on the winning probability.

Discussion

The double three-phase evaluation method of table tennis matches provides a more scientific and comprehensive perspective to analyze the competitive ability of athletes compared with the traditional three-phase evaluation method. The results of technical and tactical statistics, based on double three-phase method, are clearer and closer to the actual situation of table tennis competition, which better reflects the variation and strength of players' techniques and tactics in the competition [12].

Based on the double three-phase evaluation method, the technical and tactical diagnosis model of table tennis matches can be well established by employing BP neural network and the diagnosis model showed high precision and accuracy.

After having established the diagnosis model, according to the requirements of the athlete's technical diagnosis, a certain index value can be increased or reduced, then, input it into the neural network diagnosis model, the corresponding output value (winning probability) of the model can be obtained. Thus, it is easy to find the factors that have a significant impact on the competition result of a match and provides a theoretical reference for formulating a targeted training plan [25]. In this study, the diagnostic model was used to diagnose the techniques and tactics of Japanese famous table tennis player (Harimoto), and the results suggested that he should make full use of his advantage of active attack in the competition, and improve the quality of stalemate balls to make himself in a relatively dominant position and improve the winning probability, which supports the study of Chien et al. [27].

Although the technical and tactical diagnosis model of table tennis matches based on BP neural network had a high precision and had a good ability to analyze the technical and tactical abilities of table tennis players, there still may be some difference between the output of the model and the true competition results. Several probable factors may contribute to the difference are: (1) the training and test sample size. In this study, the training and test sample size was 70 and 30 respectively, which can be still increased for a higher model's precision [17]; (2) the selection of technical and tactical diagnosis indexes. In the study, only 30 technical and tactical analysis indexes were selected and the data were input into the model to calculate the output. There are also other factors influencing the player's competition results such as psychological and environmental elements, the opponent, and so on [28]. (3) the structure of the neural

network model, including the number of hidden layers, the number of the hidden layer's neurons, the training and transferring function, et al., which can all be changed according to the requirement of the model's precision [29]. (4) the indicator winning probability can only partly reflect the competition result of a match. Hence, the output of the diagnostic model cannot fully represent the actual competition result.

BP neural network can retain the mapping relationship between the index and the past competition result, and the technical and tactical level of athletes will change over time. When the technical and tactical level of the athlete changes, as long as the latest technical and tactical data are input into the BP neural network model, the new connection weights that reflect the current technical and tactical level of athletes can be obtained by retraining the existing neural network model. Therefore, it is necessary to track the athletes' techniques and tactics for a long time to collect new technical and tactical data to retrain the model, thus the diagnostic model can be modified and maintain a good diagnostic ability.

Conclusions

The technical and tactical diagnosis model of table tennis matches based on BP neural network had a high precision and highly efficient in fitting. It had a good ability to diagnose the technical and tactical abilities of table tennis players. By using this model, the weights of the influence of athletes' technical and tactical indexes on the winning probability of the competition can be calculated, which provides a valuable reference for formulating targeted training plans of players.

For Harimoto, the technique of attack after receive has the greatest influence on

the probability of winning, followed by the attack after serve. The stalemate technique has little effect on the winning probability.

Implication

The diagnosis model can be used to diagnose the technical and tactical characteristics of table tennis players and evaluate the strength of athletes' techniques and tactics. After the weights of the influence of athletes' technical and tactical indexes on the winning probability of the competition are calculated, the indexes that have a significant impact on the winning probability can be determined, which helps coaches to make targeted training and competition plan for table tennis players to improve the athletic ability of players.

For Harimoto, he should strengthen the training of the attack after serve and attack after receive skills, strengthen the consciousness of attack, and improve the quality of stalemate balls so as to increase the scoring rate and enhance the winning probability of competition.

Limitation

In this study, only 100 matches of the world's elite male table tennis players were selected. In the follow-up study, more matches can be selected as training samples to gain a better training and fitting accuracy of the BP neural network model. Besides, this study took only one player as an analyzing example, more players from different countries can be selected for a comparative analysis of their technical and tactical characteristics in the future study. Besides, the technical and tactical indexes did not involve specific technical action, so the suggestion proposed may not be targeted

444 enough.

445 **Declarations**

446 **• Ethics approval and consent to participate**

447 Not applicable.

448 **•Consent for publication**

449 Not applicable.

450 **•Availability of data and materials**

451 The datasets generated during the current study are not publicly available, but are
452 available from the corresponding author upon reasonable request.

453 **•Competing interests**

454 The authors declare that they have no competing interests.

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458 **•Authors' contributions**

459 All authors read and approved the final manuscript. Conceptualization, Y.X. and W.H.;
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462 and M.H.; Writing—review and editing, W.H., M.L., Y.Z., and M.H.; Supervision, Y.X.

463 **•Abbreviations**

464 BP: back propagation

465 ANN: artificial neural network

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Table 1 The thirty technical and tactical analysis indexes based on the double three-phase evaluation method

	The beginning of a game		The middle of a game		The end of a game	
Phases	Bh	Name	Bh	Name	Bh	Name
the serve and attack phase	X1	UR of Serve	X3	UR of Serve	X5	UR of Serve
	X2	SR of Serve	X4	SR of Serve	X6	SR of Serve
	X13	UR of the third stroke	X15	UR of the third stroke	X17	UR of the third stroke
	X14	SR of the third stroke	X16	SR of the third stroke	X18	SR of the third stroke
the receive and attack phase	X7	UR of Receive	X9	UR of Receive	X11	UR of Receive
	X8	SR of Receive	X10	SR of Receive	X12	SR of Receive
	X19	UR of the fourth stroke	X21	UR of the fourth stroke	X23	UR of the fourth stroke
	X20	SR of the fourth stroke	X22	SR of the fourth stroke	X24	SR of the fourth stroke
the stalemate phase	X25	UR after the fourth strokes	X27	UR after the fourth strokes	X29	UR after the fourth strokes
	X26	SR after the fourth strokes	X28	SR after the fourth strokes	X30	SR after the fourth strokes

Table 2 The error between actual and simulated values

Match No	Simulated value	Actual value	Error
No.1	0.452194	0.452200	0.000006
No.2	0.514612	0.514600	0.000012
No.3	0.333274	0.333300	0.000026
No.4	0.549943	0.550000	0.000057
No.5	0.474432	0.474500	0.000068
No.6	0.449924	0.450000	0.000076
No.7	0.426923	0.427000	0.000077
No.8	0.437415	0.437500	0.000085
No.9	0.466303	0.466200	0.000103
No.10	0.500112	0.500000	0.000112
No.11	0.402319	0.402200	0.000119
No.12	0.619540	0.619700	0.000160
No.13	0.525672	0.525500	0.000172
No.14	0.598103	0.597900	0.000203
No.15	0.464377	0.464600	0.000223
No.16	0.419550	0.419800	0.000250
No.17	0.463129	0.462800	0.000329
No.18	0.535736	0.535400	0.000336
No.19	0.464351	0.464000	0.000351
No.20	0.458779	0.459200	0.000421
No.21	0.554037	0.554600	0.000563
No.22	0.534597	0.534000	0.000597
No.23	0.300882	0.301600	0.000718
No.24	0.460113	0.459300	0.000813
No.25	0.454538	0.455400	0.000862
No.26	0.535627	0.536600	0.000973
No.27	0.536156	0.537200	0.001044
No.28	0.464899	0.466000	0.001101
No.29	0.438844	0.440000	0.001156
No.30	0.524326	0.525900	0.001574

Figures

Figure 1. Neural network model structure

Figure 1

Neural network model structure

Figure 2. Training time and error precision

Figure 2

Training time and error precision

Figure 3. Training result analysis

Figure 3

Training result analysis

Figure 4. Accuracy of the diagnostic model

Figure 4

Accuracy of the diagnostic model

Figure 5. The technical and tactical diagnostic results of Harimoto

Figure 5

The technical and tactical diagnostic results of Harimoto