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RESEARCH

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Construction and application of the technical and tactical efficiency evaluation model for table tennis matches based on grey correlation

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Abstract

Purpose By introducing the grey correlation theory to evaluate the implementation effect of various techniques and tactics of athletes, to conduct a substantial verification of the constructed "New Four-phase Index Statistical Method", to explore the scientific nature of the division of each Phase index, and to provide theoretical support for subsequent systematic research and improvement of the theoretical research system of table tennis techniques and tactics.

Methods By employing research methods such as video analysis, mathematical statistics, and grey correlation, a model of the "New Four-phase Index Statistical Method" was constructed. According to the contribution rate and total contribution rate indicators of the set tactics in the attack-after-serve phase (serve and 3rd stroke), attack-after-receive phase (receive and 4th stroke), transition phase (5th and 6th stroke) and rally phase (I and II) within the statistical model, the quality characteristics of the eight technical and tactical contributions of player T when playing against the main and reserve players of China were evaluated and analyzed.

Results the contribution rate of the first four strokes is closely related to the total contribution rate, which is the main scoring method for T to win the match. T's 5th and 6th strokes play an important role in the game of attack and defense transition, which is a key turning point of his attack-after-serve phase and attack-after-receive phase into the rally phase. The correlation between the contribution rate during T's rally phase and the overall contribution rate is not very close; similarly, the correlation between T's contribution rate and the total contribution rate is not very close either. With the multi-strokes confrontation, the advantage shown in the match began to decrease slowly.

Conclusion By introducing grey relational analysis (GRA), the various technical and tactical effectiveness of the constructed "New Four-Phase Index" can be objectively, reasonably and accurately evaluated, which has certain practicality and feasibility.

Keywords Grey correlation Analysis, Comprehensive evaluation, Table tennis Match, New four-phase index, Technical and tactical Efficiency

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Introduction

Table tennis is a competitive sport dominated by technical and tactical. It has been introduced to China for 120 years. Its development has ingrained this sport deeply within the national consciousness, often referred to as the "national ball" [1]. The reason why Chinese table tennis has been able to maintain its "long-lasting" status in the international table tennis world for a long time is that in addition to its excellent table tennis cultural tradition, the key is to attach importance to technological innovation and scientific support [2]. By constantly updating the players' technical and tactical playing system and scientific support to achieve scientific training, it has played an important role in ensuring the Chinese table tennis team's efficient participation and achievement [3]. Presently, research in table tennis competitions predominantly centers on the technical and tactical domains, given that these elements primarily dictate the competition performance of table tennis athletes, and their status is far higher than physical fitness, psychological ability and other factors [4–7]. A review of literature indicates that the focal points of table tennis technical and tactical research encompass three main areas: regular statistical analysis of table tennis technical and tactical aspects in matches, the construction of evaluation models for assessing these aspects, and diagnostic approaches for table tennis technical and tactical elements within matches [3, 8]. Of course, some scholars have also used symbolic analysis to diagnose the technical and tactical characteristics of table tennis players [9]. The Three-Phase Index Evaluation Method stands as a classic theoretical framework in the diagnosis and analysis of table tennis technical and tactical elements. Introduced by Wu Huanqun in 1988 [2], this evaluation method has persisted as a cornerstone for the assessment and diagnosis of technical and tactical aspects in racket sports, paving the way for the selection of technical and tactical indices and the establishment of evaluation models [10]. It has also provided crucial technological support for scientifically sound and objective evaluations in table tennis teams worldwide [11, 12]. However, with the continuous reform of competition rules by the International Table Tennis Federation (ITTF) and the updating of equipment (such as the transition from 38 mm celluloid balls to 40 mm + ABS plastic balls), the playing style and technical-tactical system of modern table tennis have undergone significant changes [13]. These changes have led to the predominance of multi-rally play, while the application of the classic Three—Phase Index Evaluation Method has gradually revealed certain limitations under this new system. For instance, Yang et al. pointed out in their research that the classic Three—Phase Index Evaluation method exhibits inconsistencies in the statistical data of the fifth-stroke scoring/losing points for both sides in a match [14]. This statistical deficiency indicates that the traditional method may be inadequate in coping with the complex technical and tactical variations in modern competitions. Therefore, the exploration of new table tennis technical-tactical diagnostic and evaluation models by the academic community is of particular importance to meet the demands of modern table tennis competitions.

In light of this, this study will introduce the grey correlation theory to evaluate and analyze the competitive relationship between various technical and tactical aspects of 18 important international events between the world's top table tennis player "T" and the main and reserve players of Chinese men's table tennis. However, through sorting out the literature surveyed, this study found that the research objects that researchers focus on are often mainly athletes of their own nationality, and most of them are analyzed in single games, while there are very few studies on cross—technical and tactical diagnosis and evaluation of foreign top players and Chinese main/reserve players [15]. This disparity impedes the balanced development of table tennis globally and hinders a comprehensive understanding of the dynamic developments in the competitive levels of table tennis athletes from other countries/regions. It risks fostering a closed-off environment for the exchange of scientific research on the competitive characteristics of outstanding table tennis players from various countries/regions. Therefore, there is a pressing need to intensify multidimensional research into the competitive levels between world-class table tennis players from different countries/regions and Chinese table tennis players. This effort aims to promote a more comprehensive understanding and facilitate the long-term development of table tennis on the international stage. Additionally, this study employs the initially proposed "New Four-Phase Index Statistical Analysis Method" to select various technical and tactical indicators, calculate their scoring rates and usage rates [16], and derive the contribution rates of each index [17]. Based on this, the purpose of this study is to more intuitively reflect the effectiveness of athletes' various technical and tactical by introducing grey correlation theory, so as to provide reference for the application of other sports; second, to substantively validate the "New Four-Phase Index Statistical Analysis Method" and explore its scientific basis for segmenting various index stages, thereby offering theoretical reference for the subsequent construction of the "New Four-Phase Index Evaluation Method"; finally, to evaluate the characteristics of elite table tennis players' technical and tactical from a multi—dimensional perspective, which will bring certain inspiration to the scientific training of

table tennis players in the future, and also provide certain theoretical support for further enriching the theoretical research system of table tennis.

Research objectives and methods

Selection of research samples

This study selected an elite table tennis player "T" who is currently active in the international table tennis world as the research object (Note: Considering the player's ongoing participation in various events organized by the International Table Tennis Federation, and to protect the player's competitive characteristics from disclosure, the athlete is referred to anonymously as "T"). The video of "T"'s game against the main (3 in total) and reserve (4 in total) players of the Chinese men's table tennis team was recorded as a sample for game data collection (a total of 18 games, including 10 games against the main players < 58 games, 1087 rounds >; 8 games against the reserve players < 43 games, 806 rounds >; a total of 101 games and 1893 rounds). The events in which both sides competed were critical matches in internationally significant tournaments (e.g., International Table Tennis Federation Tours, WTT World Cup, World Table Tennis Championships, and World Cup). The basic information and playing characteristics of the above players are shown in Table 1. Additionally, all match footage used in this study was sourced from official television broadcasts and online platforms. The study is conducted solely for academic research purposes and is in compliance with relevant copyright regulations. Ethical approval for this research has been obtained from the Ethics Committee of Adamson University (Approval No.: 2024–04-edu-107), and the study is strictly conducted in accordance with the requirements of the Declaration of Helsinki. All procedures adhere to the ethical guidelines of academic research, ensuring the legality and transparency of the research process.

Research methods

Video observation method

The match data utilized in this study were obtained from official high-definition video recordings of formal competitions, which were permitted and publicly broadcasted on the official websites of the International Table Tennis Federation (ITTF) (https://www.ittf.com) and CCTV-5 (https://tv.cctv.com/cctv5/). These match recordings are authorized for research analysis for non-commercial purposes and are in compliance with relevant copyright regulations. Scoring and losing points for each match were recorded based on the final shot of each point played by the athletes during the match and these were considered as observation points. For example, if after one player serves, the other player receives the serve and scores an attacking point, which would be recorded as the serving player losing the point on the third stroke, and the receiving player winning the point on the second stroke. This process was repeated for each point. The specific scoring method for one player is detailed in Table 2. Meanwhile, in order to further understand the design of observation indicators, this study uses the observation design in the study of Anguera et al. as a reference [18] and explains the definition and explanation of each observation indicator are shown in Table 3.

Table 1 Basic information on "T" and Chinese mains/reserves

Player code	Age	Height / cm	Weight / kg	Ranking	Gripping method	Opponent's type
T	24	176	68	4	righthanded, shakehand grip	double-sided reverse rubber racket, loop with fast break
main players 1	34	175	70	1	righthanded, shakehand grip	double-sided reverse rubber racket, loop with fast break
main players 2	25	170	80	2	righthanded, shakehand grip	double-sided reverse rubber racket, loop with fast break
main players 3	32	181	76	3	lefthanded, pen-hold grip	double-sided reverse rubber racket, loop with fast break
reserve players 1	26	173	80	8	righthanded, shakehand grip	double-sided reverse rubber racket, loop with fast break
reserve players 2	27	175	64	13	lefthanded, shakehand grip	double-sided reverse rubber racket, loop with fast break
reserve players 3	22	185	67	22	lefthanded, shakehand grip	double-sided reverse rubber racket, loop with fast break
reserve players 4	30	177	75	43	lefthanded, shakehand grip	double-sided reverse rubber racket, loop with fast break

The basic information data of the above athletes were obtained from the Internet search; in this study, in order to protect the competitive characteristics of the above athletes from being exposed, anonymity and code names were used to denote the athletes

Table 2 Scoring method for observational points in table tennis matches

Stroke order	Scoring Observation Point	Losing Observation Point
1st	Opponent's loss in the receive	Own loss in the serve
2nd	Opponent's loss in 3rd stroke	Own loss in receive
3rd	Opponent's loss in 4th stroke	Own loss in 3rd stroke
4th	Opponent's loss in 5th stroke	Own loss in 4th stroke
5th	Opponent's loss in 6th stroke	Own loss in 5th stroke
...	...	...

Additionally, in order to ensure the authenticity and reliability of the statistical data in this study, all the match data were collected independently by our team after unified training and proficiency in data collection methods. The original data was obtained by using the traditional match video observation method to collect the points scored and lost in the last shot of each point of both players. We also used Microsoft Excel software to design the statistical format of each observation index of each point in each game for manual recording, and summarized each point recorded in each game, and finally verified the correspondence between each point and the score of each game. Simultaneously, Simultaneously, during the data mining process, we recruited two postgraduate students majoring in table tennis, fostering their involvement in the observation and recording of the statistical data. Furthermore, through the Kappa test, a comparison was made between the data we collected and the corresponding data independently collected by the students for a subset of matches (10 matches each). $Kappa = 0.900$, $P < 0.001$. In the context of the *Kappa* value's range from −1 to 1, a higher *Kappa* value indicates better reliability between two sets of results. Therefore, the results of this study indicate good consistency in the observed data (Table 4).

"New Four-Phase Index" statistical method

The statistical method of "New Four-Phase Index" is designed and constructed on the basis of previous researches, which is different from the previous statistical methods of technical and tactical index in that the fifth and sixth strokes are classified as the transition phase, which is a crucial link for athletes to enter the rally phase (from the 7th stroke onwards) from the attack-after-serve phase (serve, the 3rd stroke) and the attack-after-receive phase (receive serve, the 4th stroke) in the match. It is of great value for evaluating the "attack—control—defense" ability of athletes in multi-stroke rallies.

The "New Four-Phase Index" are divided into the serve and attack phase (serve, 3rd stroke), the receiving phase (receiving serve, 4th stroke), the transition phase (5th stroke, 6th stroke), and the Rally Phase (Rally I Phase, Rally I Phase). The specific model of the "New Four-Phase Index" statistical method is shown in Fig. 1. In addition, according to each observed match, the data of the last stroke won/lost of each point of the athletes on both sides of the match will be recorded and statistically analyzed using the "New Four-Phase Index", and the scoring rate, usage rate and contribution rate of each shot will be calculated. The specific calculation formulas are shown in Table 5. Finally, the analysis data obtained will

Table 3 Definitions and explanations of various observation index in table tennis matches

Phase	Observational Index	Definitions and Interpretation
Attack-after-Serve Phase	Serve (the 1st stroke)	Serve (the 1st stroke) refers to the first stroke technique that is not constrained or limited by the opponent's stroke [6, 19]
	The 3rd stroke	3rd stroke refers to the stroke played by the serving player in response to the opponent's return after their serve, utilizing either an attacking or controlling technique to hit the ball
Attack-after-Receive Phase	Receive serve (the 2nd stroke)	Receive serve (the 2nd stroke) refers to the various techniques used when returning the opponent's serve [20]
	The 4th stroke	The 4th stroke refers to the techniques employed when receiving the opponent's 3rd stroke, involving various attacking and controlling techniques
Transition Phase	The 5th stroke	The 5th stroke refers to the various attack and defense transition techniques used by the serving player when receiving the opponent's 4th stroke
	The 6th stroke	The 6th stroke refers to the various attack and defense transition techniques used by the serving player when receiving the opponent's 5th stroke
Rally Phase	Rally I Phase	Rally I Phase refers to the various rally techniques used by the serving player when receiving the opponent's 6th stroke and subsequent odd-numbered strokes (including both sides maintaining the attack or one side maintaining the defense)
	Rally II Phase	Rally II Phase refers to the various rally techniques used by the serving player when receiving the opponent's 7th stroke and subsequent even-numbered strokes

Table 4 Kappa consistency test

Pairing items	Kappa value	Standard Error	z	*P*
Student & Teacher	0.900	0.095	4.045	0.000***

Note: *** represent significance levels of 1%, respectively

be analyzed using the SPSSAU (http://spssau.com) statistical software. Among them, the contribution rate of each indicator is used as the characteristic sequence (evaluation item), and the total contribution rate is used as the reference sequence (mother sequence).

Grey relational analysis method

Basic principles of grey relational degree

Grey Relational Analysis (GRA) is an integral component of grey system theory, first introduced by Professor Deng Julong in 1982 [21]. It serves as a method for quantifying the degree of association among factors within a grey system, with the core principle of assessing the correlation between factors based on the geometric similarity of sequence curves [22]. For instance, the greater the similarity in the geometric shapes of the sequence curves, the stronger the correlation between them; conversely, the less similarity, the weaker the correlation [23]. In recent years, GRA has been widely applied in the study of sports techniques and tactics, particularly in competitive sports such as basketball, volleyball, and tennis, where it effectively addresses complex relationships in technical and tactical data [24–27]. The following are the implementation steps of the Grey Relational Analysis method in the design of a technical and tactical effectiveness evaluation model for table tennis competitions:

Step 1: establishment of the original data matrix

Following Grey Relational Theory, the Grey Relational Degree evaluation model is created. Let's assume there are m reference sequences and n feature sequences, and establish the original data matrix X'_{ij} . X'_{ij}represents the numerical value of the j^{th} feature sequence of the ith reference sequence. Here, i =(1, 2, 3, 4, ..., m) and (1, 2, 3, 4, ..., n). The data sequence matrix is shown in (A).

$$X'_{ij} = \begin{bmatrix} x'_{11} & x'_{12} & \cdots & x'_{1n} \\ x'_{21} & x'_{22} & \cdots & x'_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x'_{m1} & x'_{m2} & \cdots & x'_{mn} \end{bmatrix} \quad (1)$$

Step 2: standardization of original data

Due to the diverse nature of the content reflected by indicators, lacking comparability, it is necessary to standardize the original data to eliminate the influence of dimensions and enable quantitative operations among indicators [26]. Common methods for standardization include mean normalization, initial value normalization, etc. In this study, as the data are positive indicators, mean normalization is applied [28]. The specific calculation formula is shown in (1).

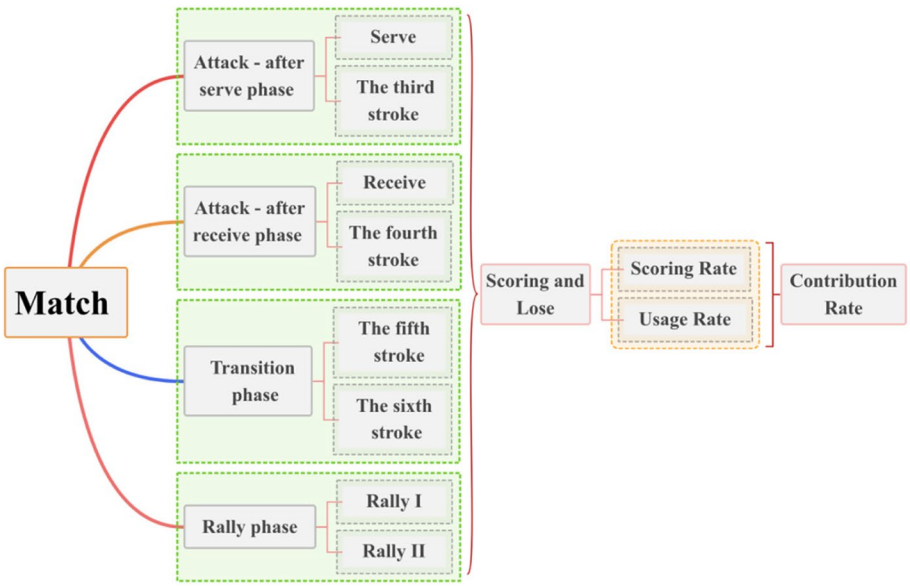

Fig. 1 Structure of the statistical model of "new four-phase index"

Table 5 Calculation formulas for various technical and tactical indices in table tennis matches

New Four-Phase Index	Secondary Index	Scoring Rate (SR)	Usage Rate (UR)
Attack-after serve phase (AASP)	serve	Direct scores from Serve / Total Serve points * 100%	Total serve points / Total strokes in attack-after-serve phase * 100%
	3rd stroke	Scores from 3rd Stroke / Total Third Stroke points * 100%	Total 3rd Stroke points/ Total strokes in attack-after-serve phase * 100%
Attack-after-receive phase (AARP)	receive	Scores from receiving / Total receiving points * 100%	Total receiving points/Total strokes in attack-after-receive Phase*100%
	4th stroke	Scores from 4th Stroke / Total 4th stroke points * 100%	Total 4th stroke points/ Total strokes in attack-after-serve phase * 100%
Transition Phase (TP)	5th stroke	Scores from 5th Stroke / Total 5th stroke points * 100%	Total 5th Stroke Points/ Total strokes in transition phase × 100%
	6th stroke	scores from 6th Stroke / Total 6th Stroke points * 100%	Total 6th Stroke Points/ Total Strokes in transition phase* 100%
Rally Phase (RP)	Rally I Phase	scores from Rally I/total Rally I points * 100%	Total Rally I points/ Total Strokes in Rally I * 100%
	Rally II Phase	scores from Rally II /total Rally II points * 100%	Total Rally II points/ Total Strokes in Rally II * 100%
Comprehensive Scoring Rate and Usage Rate		Total Points / Total Strokes * 100%	Total Strokes / Total Strokes * 100%
Contribution Rate (CR)		Scoring Rate * Usage Rate [17]	

$$X_{ij} = \frac{X_i'(j)}{\frac{1}{N}\sum_{j=1}^{N} X_i'(j)} \tag{2}$$

$$X_{ij} = \begin{bmatrix} x_1(1) & x_1(2) & \dots & x_1(n) \\ x_2(1) & x_2(2) & \dots & x_2(n) \\ \vdots & \vdots & \vdots & \vdots \\ x_m(1) & x_m(2) & \dots & x_n(n) \end{bmatrix} \tag{3}$$

Step 3: establishment of Grey relation coefficients between mother sequence and feature sequences

After standardizing the data sequences obtained from Formula (1) through mean normalization, the next step is to calculate the absolute differences between the first column reference sequence (mother sequence) and the feature sequences (evaluation items) in the standardized data sequences using Formula (2). The specific calculation Formula (2) and the absolute difference matrix (C) are as follows:

$$\triangle_{ij}(k) = \triangle_i(k) - \triangle_j(k) \tag{4}$$

$$\triangle_{ij}(k) = \begin{bmatrix} \triangle_1(k1) & \triangle_1(k2) & \dots & \triangle_1(kn) \\ \triangle_2(k1) & \triangle_2(k2) & \dots & \triangle_2(kn) \\ \vdots & \vdots & \vdots & \vdots \\ \triangle_m(k1) & \triangle_m(k2) & \dots & \triangle_m(kn) \end{bmatrix} \tag{5}$$

Here, (*k1*) to (*kn*) represent the values of various feature sequences in each row for each evaluation object.

Step 4: establishment of Grey relation coefficients

Based on the data in the absolute difference matrix (C), the maximum and minimum difference numbers are identified. These values are then substituted into Formula (6) to calculate the Grey relation coefficients. The discrimination coefficient in Formula (6) typically falls within the range of (0–1), and a common choice is 0.5 [29]. The specific formula is shown in (3).

$$\xi_{0i}(k) = \frac{\min_k |x_0(k) - x_i(k)| + \rho \times \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \rho \times \max_k |x_0(k) - x_i(k)|} \tag{6}$$

Step 5: establishment of Grey relation degree

Based on the Grey relation coefficients calculated using Formula (6) for various technical and tactical indicators of the evaluation objects, the degree of association between the feature sequences (contribution rates of various indicators) and the reference sequence (total contribution rate) can be obtained through Formula (7). A higher grey relation degree indicates a closer similarity between the feature sequences and the reference sequence [30]. The specific calculation Formula is as follows:

$$r_{0i} = \frac{1}{N}\sum_{k=1}^{N} \xi_{0i}(k) \tag{7}$$

Results

Application of the table tennis match technical and tactical efficiency evaluation model

Tactics reflect the athlete's control in the match, and the success or failure of tactical performance directly relates to the outcome of the match [9]. Strengthening the diagnosis and evaluation of athletes' various technical and tactical aspects helps athletes play to their strengths and avoid weaknesses in competitive matches. This is crucial for optimizing the technical and tactical system, realizing the positive transfer of athletes' potential advantages in tactics, and providing important guidance [31]. In this study, the data from 10 matches between T and the main players of the Chinese team are used as practical data for a detailed case analysis of the correlation calculation method. The correlation calculation method for T and the Chinese reserve players is the same. The practical data were calculated using the formulas in Table 5, resulting in the "New Four-Phase Index" contribution rates and total contribution rates. The initial analysis data are presented in Table 6.

Calculate normalized data and deviation sequences

According to Formula (1), the original data table (Table 6) is normalized, and the normalized data are shown in Table 7. Then, using Formula (2), the deviation sequences $\triangle(\max)$ and deviation sums $\triangle(min)$ are calculated based on the data in Table 7. The deviation sequence data are presented in Table 8.

Calculation of correlation coefficient and correlation degree.

According to the absolute difference sequence in Table 8, $\min k|x0(k) - xi(k)| = 0.0003$, $\max k|x0(k) - xi(k)| = 1.05$. According to previous studies, the general resolution coefficient $\rho = 0.5$ [29]. Then, the correlation coefficient can be calculated by using Formula (6). For example, taking the first absolute difference of the serve 0.0451 as an example, the calculation process is: $\xi 0i(k) = \frac{0.0003+0.5\times1.05}{0.0451+0.5\times1.05} = 0.9215$. Finally, the correlation degree between the feature sequence and the reference sequence can be obtained by calculating the average value of the calculated correlation coefficient, and the formula is shown in (5). The correlation coefficient and correlation

Table 6 The total contribution rate of each competition and the series of contribution rate of each index

total contribution rate	Attack-after-serve phase		Attack-after-receive phase		Transition phase		Rally phase	
	serve	3rd stroke	receive	4th stroke	5th stroke	6th stroke	Rally I	Rally II
0.4851	0.1724	0.4483	0.2433	0.1892	0.5	0	0.1176	0.2353
0.4522	0.3333	0.2593	0.2632	0.2369	0.2941	0.0882	0.0625	0.1875
0.5377	0.2917	0.4166	0.34	0.1714	0.3	0.1333	0.3529	0.0589
0.4874	0.0345	0.5861	0.15	0.35	0.2728	0.0909	0.25	0.1786
0.5455	0.1905	0.6667	0.2222	0.2778	0.2222	0.2222	0.0909	0.0909
0.4318	0.1923	0.4615	0.3449	0.1034	0.1667	0.1111	0.1333	0.0667
0.4216	0.1923	0.5	0.32	0.2	0.1667	0.0556	0.1818	0.0606
0.4312	0.0646	0.3549	0.282	0.1842	0.3044	0.1304	0.125	0.25
0.4803	0.1563	0.4374	0.3077	0.2307	0.2174	0.087	0.3	0.05
0.4895	0.1429	0.4762	0.2955	0.2955	0.2222	0.1111	0.2	0.1

Table 7 Normalized sequences of total contribution rates and contribution rates for each indicator in each match

total contribution rate	Attack-after-serve phase		Attack-after-receive phase		Transition phase		Rally phase	
	serve	3rd stroke	receive	4th stroke	5th stroke	6th stroke	Rally I	Rally II
1.0187	0.9736	0.9731	0.8787	0.845	1.8751	0	0.6483	1.8404
0.9495	1.8822	0.5628	0.9506	1.058	1.1029	0.8565	0.3445	1.4666
1.1291	1.6473	0.9043	1.228	0.7655	1.1251	1.2944	1.9454	0.4607
1.0234	0.1948	1.2722	0.5418	1.5631	1.0231	0.8827	1.3782	1.3969
1.1454	1.0758	1.4471	0.8025	1.2407	0.8333	2.1577	0.5011	0.711
0.9067	1.0859	1.0017	1.2457	0.4618	0.6252	1.0789	0.7348	0.5217
0.8853	1.0859	1.0853	1.1557	0.8932	0.6252	0.5399	1.0022	0.474
0.9054	0.3648	0.7703	1.0185	0.8227	1.1416	1.2663	0.6891	1.9554
1.0086	0.8827	0.9494	1.1113	1.0303	0.8153	0.8448	1.6538	0.3911
1.0279	0.807	1.0336	1.0672	1.3197	0.8333	1.0789	1.1025	0.7822

degree data of the contribution rate of each index and the total contribution rate are shown in Table 9 and Table 10.

Evaluation of tactical effectiveness for w against Chinese main players

According to the data in Table 11, it can be observed that during the matches against the main Chinese players, T demonstrated the highest tactical effectiveness on the 3rd stroke in attack-after-receive phase, with a correlation degree of 0.777. Following that, the effectiveness correlations for the attack-after-receive phase on the receive and the 4th stroke were 0.762 and 0.751, ranking second and third, respectively. The effectiveness correlations for other indicators ranked as follows: the Transition Phase (5th and 6th strokes), the attack-after-serve phase (serve), and the rally phase (rally I and rally II). Notably, T's serve demonstrated relatively lower effectiveness with a correlation degree of 0.653, indicating that T's direct scoring ability with serves was not strong, especially against Chinese main players like Xu, who demonstrated accurate judgment against T's spin serves, focusing on control (drop shot) or attack-after-receive, resulting in fewer direct points lost against T's serves. Consequently, T's serve tactical contribution quality ranked lower among the first six-stroke tactical indicators. Additionally, T performed relatively well in the transition phase (5th and 6th strokes), where effective tactical output in this phase played a pivotal role in showcasing T's overall competitive

Table 8 Absolute difference sequences of contribution rates for each indicator and total contribution rate in each match

total contribution rate	Attack-after-serve phase		Attack-after-receive phase		Transition phase		Rally phase	
	serve	3rd stroke	receive	4th stroke	5th stroke	6th stroke	Rally I	Rally II
0.0451	0.0456	0.14	0.1737	0.8564	1.0187	0.3704	0.8217	0.0451
0.9327	0.3867	0.0011	0.1085	0.1534	0.093	0.605	0.5171	0.9327
0.5182	0.2248	0.0989	0.3636	0.004	0.1653	0.8163	0.6684	0.5182
0.8286	0.2488	0.4816	0.5397	0.0003	0.1407	0.3548	0.3735	0.8286
0.0696	0.3017	0.3429	0.0953	0.3121	1.0123	0.6443	0.4344	0.0696
0.1792	0.095	0.339	0.4449	0.2815	0.1722	0.1719	0.385	0.1792
0.2006	0.2	0.2704	0.0079	0.2601	0.3454	0.1169	0.4113	0.2006
0.5406	0.1351	0.1131	0.0827	0.2362	0.3609	0.2163	1.05	0.5406
0.1259	0.0592	0.1027	0.0217	0.1933	0.1638	0.6452	0.6175	0.1259
0.2209	0.0057	0.0393	0.2918	0.1946	0.051	0.0746	0.2457	0.2209

Table 9 Results of correlation coefficient between contribution rate of each index and total contribution rate

Attack-after-serve phase		Attack-after-receive phase		Transition phase		Rally phase	
serve	3rd stroke	receive	4th stroke	5th stroke	6th stroke	Rally I	Rally II
0.9215	0.9207	0.7900	0.7519	0.3803	0.3403	0.5867	0.3901
0.3604	0.5763	0.9986	0.8292	0.7743	0.8501	0.4649	0.5041
0.5036	0.7006	0.8421	0.5912	0.9930	0.7611	0.3917	0.4402
0.3881	0.6790	0.5219	0.4934	1.0000	0.7891	0.5972	0.5847
0.8835	0.6355	0.6053	0.8470	0.6276	0.3417	0.4493	0.5476
0.7460	0.8473	0.6081	0.5417	0.6514	0.7536	0.7539	0.5773
0.7240	0.7246	0.6604	0.9858	0.6692	0.6036	0.8184	0.5611
0.4930	0.7959	0.8234	0.8644	0.6902	0.5931	0.7087	0.3336
0.8071	0.8994	0.8369	0.9609	0.7314	0.7628	0.4489	0.4598
0.7043	0.9898	0.9309	0.6431	0.7301	0.9121	0.8761	0.6817

Table 10 Correlation degree data of contribution rate of each index and total contribution rate

serve	3rd stroke	receive	4th stroke	5th stroke	6th stroke	Rally I	Rally II
0.653	0.762	0.777	0.751	0.725	0.671	0.610	0.508

Table 11 Correlation and Ranking of Total Contribution Rate and Contribution Rate of Each Tactical Indicator in Table Tennis Matches

New-four-Phase index	tactical indicator	Main players		Reserve players		Overall	
		Correlation	ranking	Correlation	ranking	Correlation	ranking
attack-after-serve phase	serve	0.653	6	0.832	4	0.744	6
	3rd stroke	0.777	1	0.836	3	0.799	2
attack-after-receive phase	receive	0.762	2	0.856	2	0.818	1
	4th stroke	0.751	3	0.858	1	0.794	3
Transition phase	5th stroke	0.725	4	0.774	6	0.772	4
	6th stroke	0.671	5	0.805	5	0.747	5
Rally phase	Rally I	0.61	7	0.757	7	0.703	7
	Rally II	0.508	8	0.655	8	0.578	8

strength. However, in the rally phase, T exhibited a relatively weaker competitive level. The main reason lies in T's playing style, which is primarily focused on fast break. The insufficient ability to sustain tactical output led to a disadvantage in the rally phase, resulting in more points lost. Moreover, Chinese main players demonstrated a relatively comprehensive tactical performances. According to Zhao's study, Chinese main players have the highest proportion of points scored in the rally phase during matches [28]. Although Zhao used the traditional "three-phase indicator evaluation method" for indicator selection, which differs from the indicator selection in this study, it can still to some extent illustrate that the Chinese table tennis team has enhanced the development of the tactical system in the rally phase in response to the demands of the International Table Tennis Federation for equipment reform. Meanwhile, combining with Fig. 2, it can be observed that T's overall tactical effectiveness against Chinese main players follows an inverted "V" trend. The ordering of T's competitive strength in various tactical indicators against Chinese main players is as follows: attack-after-serve phase (3rd stroke) > attack-after-receive phase (receive) > attack-after-receive phase (4th stroke) > transition phase (5th stroke) > transition phase (6th stroke) > attack-after-serve phase (serve) > rally phase (rally I) > rally phase (rally II). This suggests that T's scoring ability is primarily concentrated in attack-after-serve phase and attack-after-receive phase, and as the match progresses with multiple rallies, T's advantage gradually diminishes. The proportion of the contribution quality in the rally phase also decreases in comparison to the total contribution rate in the match.

Evaluation of tactical efficiency for T against Chinese reserve players

Reserve athletes are individuals aimed at achieving outstanding athletic performance in future competitions [32]. In this study, reserve players refer to those identified based on the tiered development plan of the Chinese national table tennis team [33]. Specifically, Chinese table tennis reserve players in this context have international rankings and are considered primary candidates for promotion to main players in the future. According to the data in Table 11, when T faced Chinese reserve players, the contribution rates and overall contribution rates in the attack-after-receive phase (receive, 4th stroke) were ranked first and second, respectively, indicating that these were the main scoring phases throughout the match. The third and fourth positions in terms of correlation with total contribution rates were occupied by the 3rd stroke and serve in the attack-after-serve phase. Compared to

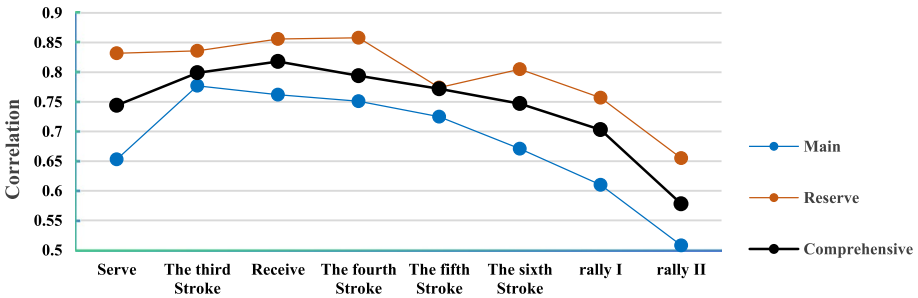

Fig. 2 Trend Chart of Table Tennis Match Tactical Efficiency Evaluation

facing main players, T demonstrated better efficiency in serving tactics when competing against Chinese reserve players, with a higher frequency of direct and effective serves. For instance, in matches against Lin and Zhou, T scored more than 11 points directly from serves. This suggests that T's effective output of tactics against Chinese reserve players is relatively stable, with clear advantages in certain techniques. This also indirectly reflects the lack of major competition experience and the need for improvement in the tactical system among Chinese reserve players. In the transition phase, T's efficiency in the 5th and 6th strokes ranked 5th (0.805) and 6th (0.774), respectively. It indicates that the 5th and 6th strokes played a role in attacking and defending transitions during the matches, similar to the results for main players discussed earlier. However, the weights of correlation with total contribution rates were higher for T compared to the main players. This is consistent with the results of Zhou's study [34] on the characteristics of board numbers. In the rally phase, T's advantage in rally tactics is not obvious, and the efficiency correlation ranks last. This reflects the fluctuation in T's continuous output of rally ability. Figure 2 illustrates that T's overall tactical efficiency against Chinese reserve players exhibits an "M"-shaped trend. The tactical system for the first four strokes is intricate, occupying the majority of the scoring weight, with similar and superior correlation weights for the first four strokes compared to other tactical indicators. The order of T's competitive strength in various tactical indicators against Chinese reserve players is as follows: attack-after-receive phase (4th stroke) > attack-after-receive phase (receive) > attack-after-serve phase (3rd stroke) > attack-after-serve phase (serve) > transition phase (6th stroke) > transition phase (5th stroke) > rally phase (rally I) > rally phase (rally II). Therefore, through correlation coefficients and trend charts, it can be concluded that attack-after-serve phase and attack-after-receive phase are crucial scoring phases for T; the 5th and 6th strokes are key points for offensive and defensive transitions, and T's rally ability is relatively insufficient.

T's comprehensive evaluation of tactical efficiency in matches

The overall correlation was calculated by combining all of T's matches against both Chinese "main team + reserve" players (18 matches). This aimed to further observe the characteristics of T's tactical application against Chinese male table tennis players. According to Table 11 and Fig. 2, the correlation of each tactical indicator of player T against the reserve players is the same as that of the main players, except that the ranking of the attack-after-receive phase (receive) and the attack-after-serve phase (3rd stroke) is opposite to that of the main players (but these two tactical indicators are the top 2 important scoring means in the technical and tactical system). Moreover, the trend lines in the line chart are similar. However, the comprehensive correlation between T and the Chinese national team's players is notably higher than that with the main players but slightly lower than that with reserve players. Examining the rankings based on comprehensive correlation reveals that T's overall competitive strength in various tactical indicators against Chinese male table tennis players is as follows: attack-after-receive phase (receive) > attack-after-serve phase (3rd stroke) > attack-after-receive phase (4th stroke) > transition phase (5th stroke) > transition phase (6th stroke) > attack-after-serve phase (serve) > rally phase (rally I) > rally phase (rally II). In summary, T's attack-after-serve phase and attack-after-receive phase are crucial advantage phases, the 5th and 6th strokes are pivotal in offensive and defensive transitions, while the rally phase is the passive phase of T during matches.

Discussions

The Value of the "New Four-Phase Index" in the Technical and Tactical Evaluation System of Table Tennis Competition

Under the new situation of the development of the table tennis technical and tactical system, in order to adapt to the changes brought about by the reform of table tennis rules, the competitive performance of long rallies between the two athletes in on-the-spot matches has become a test of athletes in many aspects such as tactics, physical fitness, and psychology. How to guide athletes to better quantitatively diagnose and evaluate the implementation effect of technical and tactical indicators is currently a hot topic in the field of table tennis performance and analysis. This has also prompted scholars to continuously innovate the construction of the table tennis match technical and tactical evaluation system. Sure, The "New Four-Phase Index" statistical analysis method was developed by our research team based on the foundation laid by previous scholars. This includes the "Three-Phase Index Evaluation Method" proposed by Wu et al. [2], the "Ten-Phase Index Evaluation Method" introduced by Li and Su [35], the "Four-Phase Index Evaluation Method" constructed by Yang and Zhang [14], the "Dynamic Three-Phase Index Statistical Method" proposed by Zhang et al. [36], the "Double Three-Phase Index Statistical Method" devised by Xiao et al. [37], and the "Interactive Three-Phase Structure" for Table Tennis by Yu and Gao [38]. The "New Four-Phase Index" method represents a novel approach to statistical analysis of technical and tactical aspects in table tennis matches. The selection of indicators in this study is based on the "New

Four-Phase Index Statistical Method," an improvement upon the "Four-Phase Index Assessment Method" developed by Yang and Zhang [14], as well as insights from Jiang et al. [11] and Zhou et al. [34] in their respective research. It is acknowledged that the 5th and 6th strokes serve as the transitional phase between offensive and defensive play and play a crucial role in the transition of attack-after-serve phase (1st and 3rd stroke) and attack-after-receive phase (2nd and 4th stroke) during table tennis matches. Therefore, this study divides the 5th and 6th stroke into transition phase, which changes the past division of these two strokes techniques into rally phases. Simultaneously, this method to some extent alleviates the issue of incongruence in statistical data between technical and tactical aspects present in the classical "Three-Phase Index Evaluation Method." Moreover, compared to several other statistical methods, it simplifies the data collection process, rendering it more accessible for novice users. Furthermore, this study takes into consideration the implementation of the ABS 40 + "new ball." Due to the reduction in ball speed and an increase in the number of rallies [39], there has been a transformation in the table tennis technical and tactical system. The emphasis has shifted from the past focus on the development of "first three strokes" techniques to a more comprehensive approach that involves technical outputs. There is a growing prevalence of rallies with more than six strokes [34]. This shift challenges traditional table tennis tactical thinking, necessitating a reevaluation and reconstruction of the table tennis technical and tactical system. Therefore, this study further refines the Rally phase, and divides it into rally I phase (odd-numbered strokes from the 7th onward) and rally II phase (even-numbered strokes from the 8th onward). Additionally, due to findings from literature reviews and data analysis indicating that rallies beyond the 7th and 8th strokes in the rally phase tend to have a relatively scattered distribution of points, for the convenience of statistical analysis and optimization of technical and tactical indicators, this study attributes the points scored and lost after the 7th and 8th strokes to the rally I phase (from the 7th stroke onward) and the rally II phase (from the 8th stroke onward) respectively. Therefore, the "New Four-Phase Index" statistical analysis method designates the 5th and 6th strokes in a match as the transition phase for separate analysis. Other phases are categorized as the attack-after-serve phase (1st and 3rd strokes), the attack-after-receive phase (2nd and 4th strokes), and the rally Phases (rally I < from the 7th stroke onward > and rally II < from the 8th stroke onward >). The advantages of this method are as follows: First, isolating the 5th and 6th strokes as a transition phase effectively demonstrates the implementation of athletes' technical and tactical strategies, aiding in real-time guidance for adjusting techniques and strategies. Second, it aligns with the requirements for reform in the table tennis technical and tactical system brought about by the International Table Tennis Federation's (ITTF) equipment changes. Third, this statistical analysis method has relatively simple steps, reducing the likelihood of data omissions and facilitating comprehension, making it suitable for novice researchers. In addition, this statistical method also provides an important theoretical basis and practical value for the next step of formulating the "New Four-Phase Index Evaluation Method".

Application effect of grey relational analysis

Grey Relational Analysis (GRA) is a novel approach for studying "small data" and "information scarcity" problems [21]. This theory provides a new statistical analysis method, namely Grey Relation Analysis, abbreviated as "GRA," which quantitatively analyzes the dynamics of evaluation objects by calculating correlation coefficients to describe the strength, size, and ranking of factors [26]. Currently, With the rapid advancement of modern information technology, the exploration of the winning laws in competitive sports and the construction of technical and tactical evaluation systems through interdisciplinary integration have become the mainstream focus of current sports research. For instance, artificial neural networks [40], decision trees [41], particle swarm optimization [42], logistic regression models [41, 43], TOPSIS comprehensive evaluation [44, 45], deep-learning theory [46], and other research methods have, to some extent, addressed the challenges posed by the complex nonlinearities in racket sports [45]. While Grey Relational Analysis (GRA) has been predominantly employed in the fields of economics and sociology, particularly in the areas of performance evaluation, decision support, and knowledge discovery [29], its application in the domain of sports has also been gradually increasing in recent years. Research studies involving sports such as basketball, volleyball, tennis, cricket, and football have demonstrated that GRA can effectively assess the correlation between technical and tactical indicators and match outcomes [24–27, 47, 48], thereby providing a scientific basis for the optimization of techniques and tactics and the formulation of training strategies. In the present study, the application of GRA in the evaluation of technical and tactical effectiveness in table tennis competitions has shown that GRA can efficiently manage complex relationships in table tennis technical and tactical data. This is largely due to the multitude of interrelated factors inherent in table tennis competitions. Therefore, GRA can objectively and effectively find out which observation indicators in the "New Four—Phase Index" are the core techniques and tactics that affect the outcome of the competition by analyzing the key factors such as the contribution rate of various

technical and tactical observation indicators in the competition and the total contribution rate of the competition results. For example, the failure of serving quality in the Attack-after-Serve Phase is likely to make it difficult for the serving side to implement the next strokes technical and tactical, but it is also possible to save the passive situation through its own changeable adjustment. Consequently, the application of Grey Relational Analysis (GRA) not only enables the identification of the correlation between athletes' technical and tactical indicators and their scoring or conceding points during competitions but also assists athletes in analyzing which techniques and tactics are crucial for scoring. This dual functionality of GRA provides an effective basis for the formulation of both competition and training strategies. In addition, GRA has an advantage in the case of insufficient data, because the table tennis match data is influenced by many factors, and there is some incompleteness. However, GRA does not need a large amount of accurate data to make a relatively objective and accurate evaluation of the technical and tactical effectiveness of table tennis competitions, and can dig out the potential technical and tactical laws and trends, which can play an auxiliary role in the adjustment of athletes tactics on the spot competition. Finally, the application of GRA is helpful to realize the technical and tactical effectiveness of table tennis competition Dynamic evaluation, because with the change of competition score and environment, the technical and tactical play of athletes will also fluctuate. For example, when one athlete leads by a big score, there may be a mentality of "seeking stability"; The athlete who lags behind in the score may implement the tactic of "fighting"; In addition, there are factors such as audiences support for athletes and coaches on-the-spot guidance, which will produce fluctuations in athletes technical and tactical effectiveness. However, this study focuses on the athletes scores. Through GRA, we can analyze the relationship between athletes technical and tactical in different implementation phases and the competition situation in real time, and find out the advantages/disadvantages of technical and tactical in time. Overall, GRA plays an important role in the evaluation of technical and tactical effectiveness of the "New Four-Phase Index" in this study, which can provide a reference price for athletes who can dominate the scientific training and competition decision-making of the net-like sports events in the future.

Limitations and prospects

The present study acknowledges certain limitations in its implementation. For instance, the sample size is relatively limited, encompassing only 18 matches of Player T against Chinese main and reserve players, which may potentially affect the generalizability of the research findings. Notably, the absence of data pertaining to female athletes restricts the broad applicability of the conclusions drawn. However, it should be emphasized that these matches are of significant international importance, characterized by a high level of competitive excellence and research value. To mitigate the limitations associated with the restricted sample size, future research endeavors may consider expanding the sample pool and integrating qualitative research methods to enhance the comprehensiveness and reliability of the study.

Additionally, while the present study did not directly quantify factors such as elite athletes' playing styles, grip techniques, and psychological fluctuations, we are acutely aware of the substantial impact these elements exert on technical and tactical performance. Grey Relational Analysis (GRA) is more adept at addressing the correlation between technical-tactical indicators and match outcomes, whereas the aforementioned factors, which are highly individualized and subjective in nature, are challenging to incorporate directly into the GRA framework. Therefore, in future research, we propose to augment the depth and breadth of our study by combining qualitative research methods, introducing multidimensional data (e.g., physiological and psychological data), and exploring the quantification of grip techniques (e.g., through motion capture technology).

Lastly, the present study did not establish evaluation criteria for the scoring rate, usage rate, or contribution rate generated during matches, and the objective assessment standards and practical utility of these metrics remain to be validated. Consequently, we will continue to refine and enhance the "New Four-Phase Index Statistical Method" in future research to improve its applicability in both research and practice.

Conclusion

1) T's playing style is primarily characterized by "fast-break," with mature technical connections and versatile tactics. The tactical play of the first four strokes constitutes the main scoring method for winning matches, and there is a close relationship between the contribution rate in these initial four strokes and the overall contribution rate in matches. The correlation weight of the first four strokes' tactical play is higher than that of other tactical indicators. T's tactical performance is influenced by opponents of varying technical levels; the more evenly matched the opponent, the more stable T's tactical performance, allowing their advantageous techniques to stand out. Conversely, when facing opponents with weaker technical, T's performance tends to be different.

2) T's 5th and 6th strokes play a crucial role in offensive and defensive transition, serving as important turning points from attack-after-serve and attack-after-receive phases to the the rally phase. However, in the rally phase, T's advantage is not significant. The tactical effectiveness correlation rank is the lowest in this phase, with a relatively low weight. As the rally progresses through multiple strokes, T's advantage gradually diminishes.
3) The development of the "New Four-Phase Index Statistical Method" provides valuable insights for further screening, constructing, and evaluating athletes' tactical indicators. From the perspective of contribution rates, the introduction of Grey relational analysis allows for an objective, rational, and accurate assessment of the tactical effectiveness of various indicators. This method can effectively reflect the strengths and weaknesses of athletes in tactical performance, providing valuable guidance for coaching, training, and pre-match strategies.

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Author contributions
HG Y was responsible for the writing of the manuscript; X C and L Z were responsible for the revision of the manuscript; YX Z were responsible for the processing of the original data; and L Z was responsible for language polishing and revision.

Authors' contributions
HG Y was responsible for the writing of the manuscript; X C and L Z were responsible for the revision of the manuscript; YX Z were responsible for the processing of the original data; and L Z was responsible for language polishing and revision.

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Data availability
The Datasets used and / or analyzed during the current study are available from the first and corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
All procedures were in full compliance with the declaration of Helsinki, and this study was approved by the ethics committee of Adamson University (Approval No.: 2024–04-edu-107).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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