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Research on Relative Space Effectiveness of Badminton Match—Three-Dimensional Space Division of Badminton Court

Bin Zhang[1], Yibo Zhang[2*]

[1]College of Physical Education and Health Sciences, Zhejiang Normal University, Jinhua, China
[2]School of Physical Education and Health Engineering, Taiyuan University of Technology, Taiyuan, China
Email: *zhangyibo@tyut.edu.cn

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Abstract

The three-dimensional space of the badminton court is divided, and with the help of the technique effectiveness calculation formula, it is proposed to analyze the game using relative space effectiveness. Using computer programming technology to solve the calculation deviation caused by taking a balance point slightly lower than the average score rate, making the calculation more accurate and efficient. The case analysis takes the women's singles game as the unit, calculates the effectiveness values of the athletes of the two sides in different spaces, compares the relative space effectiveness of the athletes of both sides, and analyzes the impact of different spaces on the outcome of the game. Research shows that the method of recording data using relative space is reliable and take the relative space effectiveness value of 0.5 as the benchmark to reflect the contribution of space hitting to winning; the difference between the relative space effectiveness of the winner and the loser in the transition space is the largest. Although the loser can occupy a certain advantage in the defensive space, the gap between the effectiveness value in the transition space and the offense space is greater than the winner; the back court space offense effectiveness is the key to the success of the women's singles game.

Subject Areas

Sports Science

Keywords

Badminton, Relative Space, Effectiveness Calculation, Balance Point

1. Introduction

Scoring rate and usage rate are commonly used data metrics for analyzing matches in net sports (racket sports). Previous studies on sports like table tennis, badminton, and tennis have primarily focused on analyzing and evaluating athletes' tactics and strategies through scoring rate and usage rate [1] [2]. The scoring rate reflects the quality of match performance, while the usage rate reflects the quantity of match performance. Match analysis needs to consider both quality and quantity factors. However, in practice, there exists an inconsistency between high or low scoring rates and usage rates. To address this issue, Zhang Hui *et al.* [3] proposed the concept of technical efficiency, which constructs an efficiency formula for technical usage based on scoring rate and usage rate, allowing for a comprehensive analysis and evaluation of athletes' match performance from both quality and quantity perspectives.

Space is one of the forms of material existence, and in sports competitions, spatial factors play a crucial role in tactical activities [4]. Badminton exhibits typical three-dimensional spatial characteristics, and analyzing the tactics and strategies of badminton players from a three-dimensional spatial perspective can provide an intuitive reflection of the rules of the sport and the individual characteristics of athletes. Ren Yahui *et al.* [5] introduced the concept of spatial utility to quantify the decision-making effectiveness of athletes in different spatial zones, which has provided new ideas and methods for research. However, their method of dividing three-dimensional space presents some practical challenges. The application of the benefit values calculated from different stroke techniques to the calculation of spatial utility and the classification standards of technical properties requires further refinement.

In light of this, the study proposes the use of "relative spatial efficiency" to analyze athletes' match behaviors in different spatial zones, leveraging the rationality and accuracy of the technical efficiency formula, the intuitive advantages of analyzing matches from a spatial perspective, and practical methods for spatial division. Relative spatial efficiency, inspired by the mathematical formula used to calculate technical efficiency, directly calculates the athlete's efficiency in different relative spaces and is used to analyze and evaluate the athlete's tactical behaviors in these spatial zones. The term "relative space" refers to the fact that when dividing the three-dimensional space, the height of the shot is considered relative to the athlete's body parts rather than an absolute scale. The concept of relative shot height has always existed in badminton theory and practice, used to describe the position of the shot, such as low and high shot positions [6] [7]. Cheng Yongmin, a coach with the Chinese National Badminton Team, suggested that using body parts as a reference to record the shot position can achieve relative accuracy. Using a relative scale to record the spatial position of the shot not only aligns with the characteristics of the sport but also facilitates practical implementation.

2. Spatial Division of the Badminton Court

The division of the three-dimensional space of the badminton court forms the foundation of the study on relative spatial efficiency, involving the accuracy of observation by personnel and the reproducibility of the research. Therefore, the study discusses the principles of spatial division, the reliability of observation records, and the methods for data recording.

2.1. Current Situation of Court Division

Current research on the division of the badminton court is primarily conducted within a two-dimensional plane. Depending on the needs, both domestic and international studies generally divide the badminton court space into 6 to 12 different regions to record the athlete's service area, hitting positions, landing points, etc. Studies typically divide the court evenly or refer to the various boundary lines of the court to divide the half-court into 9 regions [8] [9]. Some scholars have identified 10 regions for doubles serve-receive areas [10], and some even subdivide it into 20 regions [11]. Foreign studies typically further subdivide the front, middle, and back courts into 6 or 8 regions [12] [13], with some studies dividing them evenly into 12 hitting positions [14].

Currently, there is limited research on the three-dimensional division of the court space. In fact, based on the two-dimensional division used to record hitting positions, the method of simultaneously recording the airborne hitting points from low, side, and high positions [7] can also be considered a form of three-dimensional division of the match space, although the hitting position and hitting point records are kept separate. Ren Yahui, Shen Lejun, and others [5] divided the length and width of the badminton court evenly, and based on the standards of 1.55 meters and 2.5 meters, they divided the court into three layers from low to high, thus forming the three-dimensional space of the badminton court. This method, which uses absolute scales to divide the three-dimensional space of the badminton court, has the advantage of allowing for analysis of the athlete's hitting points and spatial behavior, providing an objective basis for division. However, it still needs further improvement for practical application.

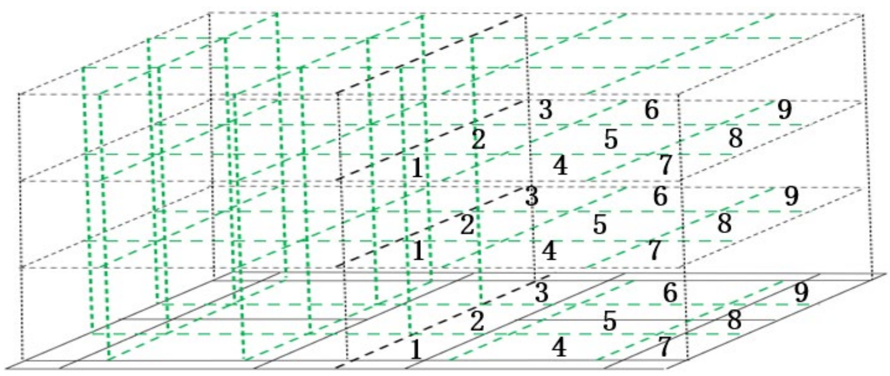
Firstly, the three-dimensional court space division using absolute scales does not fully align with the characteristics of the badminton sport. The height of the front and back courts in badminton is difficult to be measured using the same scale, which is determined by the athlete's technical usage and the nature of the sport. For example, using 1.55 meters as a standard, this height is relatively high for the front court, but relatively low for the back court. Moreover, within this height range, a shot in the front court could be a low flick or a high push, indicating that the height division and technical usage characteristics differ significantly. Furthermore, within the same region, due to the differences in athletes' physical conditions, using an absolute height scale is difficult to apply universally to all athletes. Although an athlete's shot is influenced by the spatial height, the more important factor is the athlete's relative spatial position to the hitting point. Therefore, the height division scales used in individual case studies are specific and are difficult to generalize for measuring all athletes' shots. Finally, given the current technology, using absolute scales for precise division is difficult, making practical application inconvenient. Not only does it require expensive specialized equipment, but the efficiency of processing large amounts of data also needs continuous improvement.

2.2. Relative Scale Spatial Division and Data Recording

2.2.1. Relative Scale Spatial Division

The use of tactics and strategies by athletes during a match is not only determined by the opponent's situation but is also limited by the athlete's position on the court and their relative spatial position to the shuttlecock. Based on the spatial characteristics of badminton, the distribution of the front and back areas of the court, as well as the heights in certain areas, are not uniform. The perception of space is based on the relative positions between space and objects, which is why the concept of relative scale spatial division is proposed.

Firstly, based on the general understanding and division methods of the badminton court, and using ground markings such as the front and back service lines as references, the court is divided into nine areas: front, middle, and back, and left, middle, and right. Furthermore, the relative aspect of this division mainly reflects in the height classification. Based on the typical height of hitting points in badminton, they are generally divided into high position, middle-high position (side position), and low position. In addition, hitting at the high position is considered an active shot, the middle-high (side) position is considered a semi-active shot, and the low position is considered a passive shot. To better correspond to the hitting height and shot characteristics and to facilitate practical application, the study adjusts the height division of the front court: the top third of the net is considered the high point, while below the net is the low point, with the middle point corresponding to the area between the high and low points. For the backcourt, the high point is above the head, the low point is below the shoulder joint, and the middle point corresponds to the midpoint between the two.



Note: The left side shows the specific spatial division, while the right side illustrates the three layers (low, middle, high) and the subdivision numbers for each layer.

Figure 1. Schematic diagram of the three-dimensional spatial division of the court.

Through the above division, three spatial layers are formed from low to high. Each layer includes nine subdivided spaces, resulting in a total of 27 different hitting spaces. Both players complete their shots within the 27 three-dimensional spaces across the low, middle, and high layers of their respective half-courts. For ease of explanation, each space in a layer is numbered from 1 to 9, starting from the front left area to the back right area, as shown in Figure 1.

2.2.2. Principles of Observation and Recording

Due to the differences in athletes' body types, the divided spaces are relative, while there is a unified division standard within the relative system that can be applied to all athletes. The absolute height of the hitting point varies due to differences in height, as well as factors such as shot variation and force. Therefore, athletes' shot choices and outcomes in different spaces vary. Athletes' shot choices and outcomes are constrained by the relationship between the shuttlecock and their body position. Analyzing an athlete's shot from a relative spatial perspective can reflect their individual characteristics and athletic traits.

In practice, there is a problem in defining shots in the boundary areas between different body shapes and heights. It has been proven in practical operation that standardizing the process and clarifying division criteria can enhance the reliability of the records. The following principles should be referred to when observing and recording the hitting point:

1) Unless the hitting point can be clearly distinguished, the hitting point should be confirmed repeatedly using slow motion or pause features. The athlete's joint positions and the court markings should be referenced to help identify the spatial location of the hitting point, improving observation accuracy and speed.

2) The attribution of the hitting point's space is related to the nature of the shot. When the hitting point is at the boundary between different shot heights and the shot trajectory is parallel or downward and has an attacking nature, the shot is attributed to the higher hitting space; otherwise, it is attributed to the lower space.

3) The attribution of the hitting point's space is related to the hitting technique and body movement. When the hitting point is at the boundary between the front and back regions and the athlete shows a tendency to move forward, adopting front-court hitting techniques, the shot is attributed to the front court; otherwise, it is attributed to the middle court. The distinction between middle and back courts is similar.

4) The attribution of the hitting point's space is related to the extension of the arm and the direction of the shot. Whether the athlete clearly extends the arm to both sides to distinguish between left, middle, and right, and the direction of the shot, should be considered. For example, if the opponent hits in the middle area and the player hits a straight shot, it is attributed to the middle area, whereas a small diagonal shot toward the right side would be attributed to the right area.

2.2.3. Reliability of Data Recorded Using Relative Spatial Method

Reliability refers to the consistency or stability of the observation and measurement process. In marking analysis, reliability is typically evaluated through internal and external consistency of the observers [15]-[17]. To validate the reliability of this spatial division method for recording data, a statistical analysis was conducted on the women's singles semifinal of the 2019 BWF World Tour Finals, where Tai Tzu-ying won 2-0 against Akane Yamaguchi, with scores of 21 - 15 and 21 - 18 in the two sets.

Before performing video analysis, the concepts were repeatedly reviewed, and the process was familiarized with them. Independent statistics were recorded by different personnel, and then the statistics were repeated one week later. The consistency of the data was evaluated using the Kappa consistency test. The results showed that the Kappa coefficients for the consistency of data between the first and second sets of independent personnel were 0.824 and 0.803, respectively, while the consistency of data recorded by the same person in two separate instances was 0.921 and 0.818. The consistency test indicated a strong consistency between the two sets of data, confirming that the method of recording athletes' hitting conditions in relative scale space is reliable.

3. Relative Spatial Efficiency Calculation

3.1. Calculation Formula

The calculation of classic technical efficiency uses a scoring rate of 0.5 as the equilibrium point, and the technical efficiency function TE is expressed through the fitting of a mathematical function:

$$TE = -\left(1+\frac{\sqrt{2}}{2}\right)+\left(1.5+\sqrt{2}\right)\left[\left(1+y\right)^{x-0.5}\right]-\frac{\sqrt{2}}{2}\left[\left(1+y\right)^{2(x-0.5)}\right] \quad (1)$$

The TE value satisfies specific related attribute requirements. In actual situations, athletes exhibit different attributes in various offensive and defensive behaviors during the match, and the difficulty of scoring can vary significantly. A single equilibrium point cannot fully reflect the reality. Therefore, Zhang Hui *et al.* [3] evolved the technical efficiency calculation method. In practical applications, the equilibrium point value is adjusted based on the attributes of the match behavior, and multiple technical efficiency calculation formulas with different equilibrium point values are provided to meet real-world applications.

Space is one of the forms of tactical performance and serves as the basis for incorporating the athlete's tactical behavior into various hitting spaces. The calculation method for relative spatial efficiency (RSE) draws from the technical efficiency formula and analyzes the athlete's tactical behavior in different spaces through spatial efficiency. The relative spatial efficiency (RSE) is calculated based on the scoring rate and usage rate of each space:

$$RSE = A + B\left[\left(1+y\right)^{x-\alpha}\right]-C\left[\left(1+y\right)^{2(x-\alpha)}\right] \quad (2)$$

Where: x is the spatial scoring rate ($0 \le x \le 1$); y is the spatial usage rate ($0 \le y \le 1$); α is the equilibrium point (equal to the average scoring rate); A, B, and C are constants corresponding to different equilibrium point values that satisfy the properties of *RSE* (Huang Wenwen *et al.*, 2014).

The overall RSE satisfies the following properties:

(1) $0 \le RSE \le 1$, the larger the *RSE* value, the higher the relative spatial efficiency of that space.

(2) When $x = \alpha$, regardless of y, the *RSE* value is always 0.5.

(3) When $x > \alpha$, *RSE* is an increasing function of y. When $x = 1$ and $y = 1$, the relative spatial efficiency reaches its maximum, *i.e.*, the *RSE* value is 1.

(4) When $x < \alpha$, *RSE* is a decreasing function of y. When $x = 0$ and $y = 1$, the relative spatial efficiency is at its minimum, *i.e.*, the *RSE* value is 0.

(5) When $y = 0$, it indicates that the athlete did not hit in the corresponding space, and the *RSE* value is also 0.5.

3.2. Selection of the Equilibrium Point

The equilibrium point is selected as the average scoring rate of the overall shots in a given space. Since the offensive and defensive attributes of shots in different spaces vary, different equilibrium points should be used in the calculation of relative spatial efficiency. The average scoring rate of a space represents the average level of scoring ability of different athletes in that space. When an athlete's scoring rate in a particular space is higher than the average level, it indicates that this space has a positive impact on winning the match. Conversely, when an athlete's scoring rate in a particular space is lower than the average level, it suggests that this space has a negative impact on winning the match. Therefore, selecting the average scoring rate of the space as the equilibrium point for calculating efficiency in different spaces is reasonable.

3.3. Optimization of the Calculation Method

The calculation of relative spatial efficiency is divided into two steps. First, the constants are calculated based on the equilibrium point, and then these constants are substituted into the formula to calculate the efficiency value. In the relative spatial efficiency calculation, the equilibrium point is selected based on the average scoring rate of each space. Then, the constants A, B, and C for the relative spatial efficiency formula are calculated according to the five requirements of the overall properties of relative spatial efficiency. The corresponding constants are then substituted into the formula to calculate the relative spatial efficiency based on the scoring rate and usage rate of different athletes in each space.

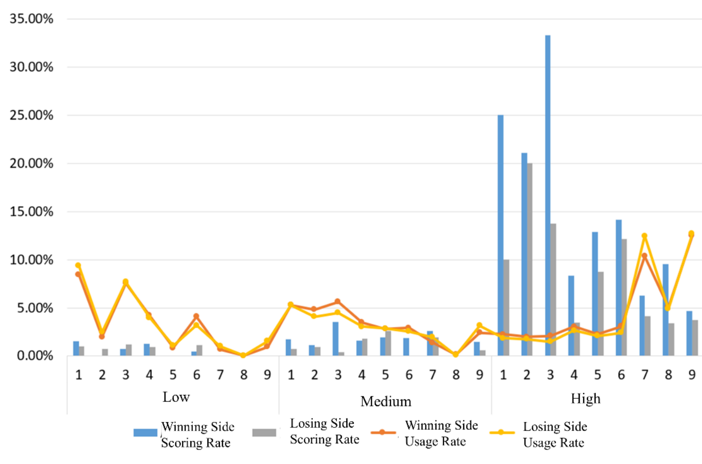
The use of computer programming technology can optimize the calculation process. Since the calculation process is complex and requires multiple iterations to compute the constants A, B, C, and the final efficiency, the study utilizes computer programming technology to achieve automatic calculations, greatly improving the speed and accuracy of the calculations. The calculation process is divided into two parts: first, the equilibrium point is input, and the computer automatically derives the constant values; then, the scoring rate and usage rate are input to calculate the final efficiency value. The study uses Visual Studio 2019 to compile and run the program, adopt the algorithmic approach of solving equations, and utilize mathematical library functions to perform the calculations. Finally, the output results are controlled by C++ language.

In the past, the method of selecting a balance point slightly lower than the average scoring rate for efficiency calculation [3] [18] could result in some deviations under certain special circumstances. For example, when the average scoring rate is 0.526 and the balance point is set at 0.5 for the technical efficiency calculation formula, if an athlete's scoring rate is 0.515, the calculation result may deviate from the actual situation. Theoretically, the athlete's efficiency value should be a decreasing function of usage rate, but the actual calculation results in an increasing function. Therefore, the use of computer programming not only improves the calculation speed but, more importantly, ensures that the results are more reasonable and accurate.

Unlike the approach that only observes and records the final shot of a rally, this study records each shot. The scoring rate, usage rate, and the athlete's shots are all related. A score is the result of multiple shots from a tactical combination executed by the athlete. During the hitting process, various situations such as active and passive shots are included in the form of space. Therefore, the final shot results are integrated into the spatial outcome, and the spatial efficiency derived is related to all shots within that space.

4. Case Analysis of the Application of Relative Spatial Efficiency

The study selected video footage from the women's singles matches of major badminton competitions, including the World Badminton Championships and the China Badminton Open, within the top 8 rankings over the past two years. A total of 15 matches and 40 sets were analyzed, with a total of 13,835 shots taken by both competitors. The video observation considered each individual shot as the unit of observation, recording the relative spatial location of each shot as well as the results for both players (Figure 2).



Note: Spatial usage rate = number of shots in a given space/total number of shots in all spaces × 100%.

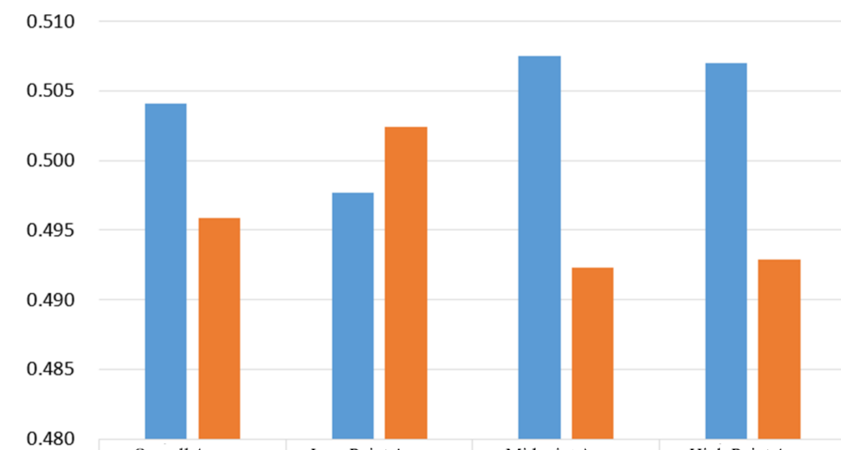
Figure 2. Scoring rate and usage rate in different spaces.

Spatial Scoring Rate = Number of scored shots in a given space/Number of shots in that space × 100%

Previous studies have explained athletes' performance using metrics such as scoring rate and usage rate. From Figure 3, it can be observed that the distribution of scoring rate and usage rate in different height spaces for both winners and losers follows a certain pattern, but the changes in scoring rate and usage rate are not consistent. The scoring rate generally increases with the height of the shot. The high positions in spaces 1, 2, and 3, located in the front court, have the highest scoring rate, but their usage rate is not high. The usage rate is higher in spaces 1, 3, and 6 at the low and middle points, while in the high positions, it is higher in spaces 7, 8, and 9, located in the back court. Analyzing the spatial characteristics of a badminton match requires considering both qualitative and quantitative indicators. By combining scoring rate and usage rate to calculate relative spatial efficiency, a more intuitive and accurate analysis of the athlete's performance in different spaces can be achieved.

To calculate the relative spatial efficiency, the case analysis first calculates the average scoring rate and usage rate of different spaces, then selects the appropriate equilibrium point to calculate the athlete's relative spatial efficiency. The following analysis focuses on the athlete's shots in different spaces, comparing the relative spatial efficiency of the winner and loser at the overall and specific subdivided spatial levels, using the set as the unit of comparison.

4.1. Overall Analysis of Relative Spatial Efficiency



	Overall Average	Low Point Average	Midpoint Average	High Point Average
Winning Side RSE	0.504059	0.497663	0.507511	0.507002
Losing Side RSE	0.495878	0.502399	0.492323	0.492911

Winning Side RSE   Losing Side RSE

Figure 3. Overall distribution of relative spatial efficiency.

Relative to low-point spaces, which are primarily defensive, and high-point spaces, which are mainly offensive, shots in the middle-point space are in a transitional position between offense and defense. Based on the nature of this shot distribution, previous studies have classified these spaces as defensive space, transitional space, and offensive space [5]. When dividing relative spaces, the different shot properties are taken into account, thus the connection between shot height division and the offensive/defensive attributes of shots becomes more closely related.

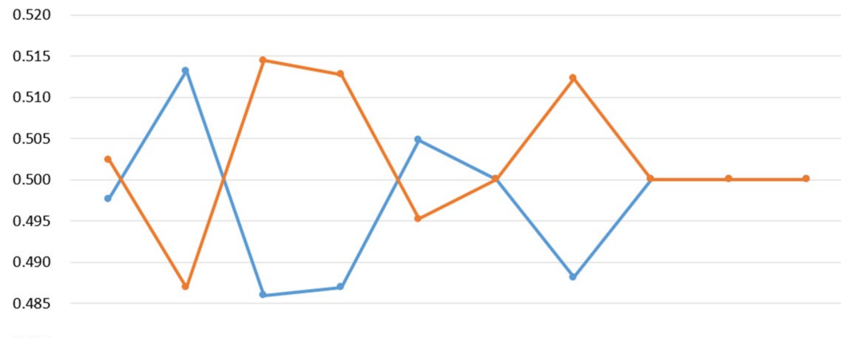
Since the calculation of relative spatial efficiency uses the average scoring rate as the equilibrium point, the efficiency values for each space of both the winner and the loser will fluctuate around 0.5 based on the properties of the calculation formula. In cases where the overall difference in usage rate between both sides is not significant, the efficiency values for each space will be symmetrically (though not perfectly symmetrical) centered around 0.5. A value greater than 0.5 indicates that the shots in that space are beneficial for winning, while a value less than 0.5 suggests they are detrimental. Moreover, when analyzing by set, theoretically, the winner's score will always be higher than the loser's, so the winner's efficiency value will generally be higher. However, there are cases where the efficiency value for a particular space may be higher for the loser than the winner.

A comparison of the data shows that in **Figure 4**, the overall relative spatial efficiency of the winner is significantly higher than that of the loser, which is consistent with the match outcome. However, it is noteworthy that in defensive spaces, the relative spatial efficiency of the loser is higher. In contrast, the winner performs better in offensive and transitional spaces, and the margin by which the winner's efficiency exceeds that of the loser in these spaces is significantly greater than the margin by which the loser outperforms the winner in the defensive space. This suggests that in offensive and transitional spaces, the side with the higher efficiency is more likely to win, because the shots in these spaces tend to have a higher height, making the offensive play more aggressive.

Chen Tao *et al.* [19] argue that strengthening continuous attacks in the backcourt, limiting net play techniques, and enhancing offensive capabilities are key trends for success in women's singles. The relative spatial efficiency also reflects the importance of offense in women's singles. From a spatial perspective, the competition for control of transitional and offensive spaces plays a more significant role in determining the outcome of modern high-level women's singles badminton matches. To enhance offense and limit the opponent, one must take control of the space. Athletes should aim to occupy relatively higher hitting spaces during the match to increase the threat of their shots, as hitting from high positions allows them to execute the correct attacking routes, expand the opponent's defensive area, and create opportunities for scoring and taking the initiative [20] [21].

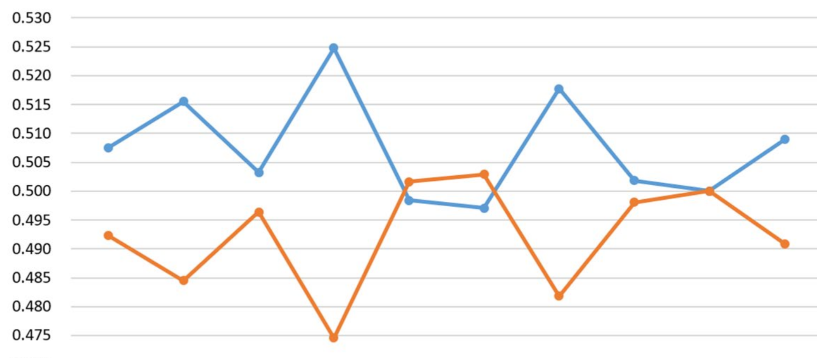
4.2. Specific Analysis of Relative Spatial Efficiency

By examining both sides' scoring rates and usage rates, it was found that in defensive spaces, the loser's spatial scoring rate and usage rate were 5.00% and 30.26%, respectively, both of which are slightly higher than those of the winner. As a result, the relative spatial efficiency of the loser in defensive spaces is higher. The losing player made more shots in defensive spaces, indicating that they were in a defensive state more frequently during the match, responding to the opponent's attacks. Looking at the relative spatial efficiency of the different low-point spaces, there is no difference between the winner and the loser in spaces 5, 7, 8, and 9. The reason the loser has a higher spatial efficiency at low points mainly lies in the higher efficiency values in spaces 2, 3, and 6. These three positions are primarily on the right side of the front and middle courts, which, for right-handed players, are forehand positions. This suggests that players generally find it more advantageous to defend from the forehand position, and they can even score from there. There are four spaces with a relative spatial efficiency of 0.5, located in the middle and back courts. The low-point backcourt spaces generally have fewer shots. When the opponent attacks these spaces, it is mostly through direct scoring, with only a few returns, but the number of scored shots is almost zero (Figure 5).



	Low Point Average	1	2	3	4	5	6	7	8	9
Winning Side RSE	0.497663	0.513172	0.485947	0.486933	0.504783	0.5	0.488136	0.5	0.5	0.5
Losing Side RSE	0.502399	0.486923	0.514458	0.512728	0.495211	0.5	0.512274	0.5	0.5	0.5

Figure 4. Distribution of relative spatial efficiency in low-point (Defensive Space).

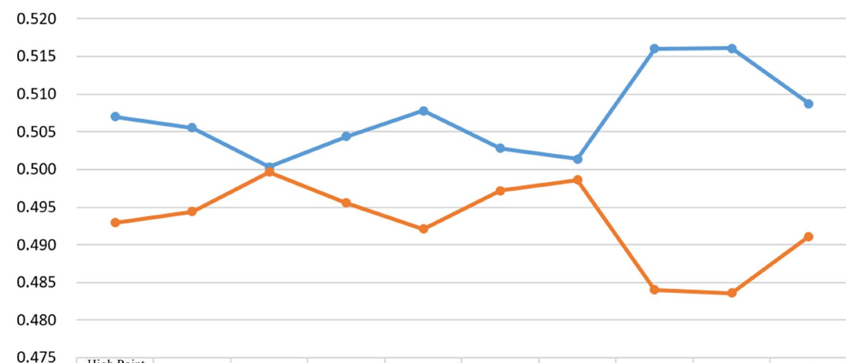


	Midpoint Average	1	2	3	4	5	6	7	8	9
Winning Side RSE	0.507511	0.515519	0.503265	0.524799	0.498407	0.497081	0.517731	0.501851	0.5	0.508945
Losing Side RSE	0.492323	0.484506	0.496390	0.474597	0.501662	0.502940	0.481827	0.498090	0.5	0.490899

Figure 5. Distribution of relative spatial efficiency in mid-point (Transitional Space).

From the overall spatial efficiency perspective, the winner's efficiency in the transitional space is the highest among the three height spaces, and the winner has a clear advantage in this space. Compared to the high usage rate of the loser in defensive spaces, the winner makes more shots in transitional and offensive spaces. This indicates that the winner, through active movement, raised their hitting points and converted some passive defensive shots into transitional or even offensive shots, thus implementing the commonly used "defend and counterattack" tactic [22]. Nowadays, female badminton players are more proactive in defense, aiming for higher hitting points to increase the speed of counterattacks, thereby enhancing the aggressiveness and better limiting the opponent. This study on relative spatial efficiency also confirms this point.

Another important role of shots in the transitional space is that when there is no good attacking opportunity, both sides often use transitional shots to create chances. In the 9 transitional spaces, the winner has a higher relative spatial efficiency in 6 of them, either slightly or significantly higher than the loser, indicating that the winner is more reasonable in handling transitional shots. From the results of relative spatial efficiency, first, there are relatively more points scored from shots in the transitional space. Secondly, by striving for relatively higher hitting points, players can achieve better transitional shots. Cheng Yongmin [23] pointed out that when an athlete achieves a higher hitting point, it increases the difficulty for the opponent to return the shot. Better shots in the transitional space not only reduce the chances of the opponent scoring, but also lay the foundation for the next tactical organization, and even directly create attacking opportunities. Therefore, shots in the transitional space play an important role in determining the outcome of the match (Figure 6).



	High Point Average	1	2	3	4	5	6	7	8	9
Winning Side RSE	0.507002	0.505514	0.500327	0.504370	0.507778	0.502791	0.501370	0.516033	0.516083	0.508750
Losing Side RSE	0.492911	0.494399	0.499665	0.495561	0.492079	0.497168	0.498593	0.484010	0.483614	0.491113

Figure 6. Distribution of relative spatial efficiency in high-point (Offensive Space).

The offensive efficiency of modern women's singles players has a direct impact on the outcome of the match. Strengthening offensive ability and improving offensive effectiveness are key to winning the match [19]. The efficiency values in offensive spaces comprehensively reflect both the quality and quantity of the athlete's offense. By comparing these, the gap between the winner and the loser in specific offensive spaces can be observed, deepening the understanding of the dynamics of women's singles. In the match, offensive spaces carry the athlete's primary direct offensive actions. Comparing the two sides, it is evident that the winner's spatial efficiency is higher in all offensive spaces than the loser's, showing that offensive space directly influences the outcome of the match. From the overall trend of offensive space efficiency, it can be seen that the winner's efficiency generally increases from the front court to the back court, while the loser's trend is the opposite [24]-[28].

There is a significant difference in efficiency values between both sides in the backcourt baseline spaces 7, 8, and 9, with the greatest gap in space 7, which is generally at the athlete's overhead position. It can be seen that the difference in efficiency values between the winner and loser in this space is second only to that in space 8. Since space 8 is located in the middle of the backcourt, its usage rate is much lower than that of spaces 7 and 9 on the sides. Therefore, the most influential space on the outcome of the match in offensive areas is space 7. The efficiency values from the three baseline spaces also reflect the importance of baseline offense, particularly the overhead position, in modern women's singles. Cheng Yongmin, a research coach with the Chinese National Badminton Team, believes that the current style of women's singles is more aggressive, with increasingly powerful backhand techniques, fiercer overhead shots, and stronger baseline attacks [29] [30]. The distribution of relative spatial efficiency in the backcourt for both the winner and the loser also reflects these characteristics.

5. Summary and Outlook

5.1. Summary

1) Based on previous research, this study reviewed the different methods of badminton court division. While meeting basic research requirements, it extended the previous two-dimensional division of the court into nine regions by incorporating the athlete's hitting height, leading to a relative spatial division of the badminton court, and discussed its rationality.

2) By using computer programming technology, the study enabled fast and accurate calculation of spatial efficiency, avoiding calculation errors that can occur when using an equilibrium point below the average scoring rate in certain special cases.

3) From a spatial perspective, this approach provides an intuitive display of how both sides use space during a badminton match. By comparing the efficiency differences between the winner and loser in different spaces, it contributes to exploring the rules of women's singles. Using an efficiency value of 0.5 as the baseline, the study reflects whether hitting from a specific space is beneficial for winning. Comparative analysis found that the transitional space efficiency was the greatest advantage for the winner. Although the loser had better relative spatial efficiency in the defensive space, they lagged significantly behind in the more impactful transitional and offensive spaces.

4) In offensive spaces, the efficiency gap in the backcourt between the winner and loser was large, indicating that the efficiency of backcourt space offense is the

key factor in determining the outcome of women's singles matches.

5.2. Outlook

Starting from the three-dimensional spatial perspective and considering the characteristics of the sport along with practical application convenience, the use of relative spatial efficiency to analyze badminton matches is feasible. Due to differences between the various disciplines in badminton, further research is needed on the spatial division and spatial efficiency rules for other disciplines.

The division of relative space is more convenient for practical application. Based on previous research, different quantities of spatial divisions can be made to meet the needs of different studies. The ease of applying relative spatial analysis enables statistical analysis of large datasets, providing support for future research in badminton match analysis, athlete tactical evaluations, database development, and other areas.

Conflicts of Interest

The authors declare no conflicts of interest.

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