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Research Article

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Several discussions on the training methods of badminton in our country on the basis of mathematical model

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ABSTRACT

On the basis of analytical hierarchy process (AHP), this paper makes an analysis of badminton from four aspects: physical quality, spirit of cooperation, reaction quality and innovation ability. This paper concludes that humanities training accounts for 44.7% whereas physical training accounts for 55.3% in badminton, which demonstrates that badminton is not just a sport of challenging physical limits, but the one which calls for technics, skills and so forth. After a geometric model is established, this paper discusses that when an athlete spikes, he or she should try to keep the arms straight in front and vertical to the striking point. The higher he or she jumps, the more likely that ball can pass over the net. And the height of the striking point determines the trajectory and landing point of the ball. Thus, according to different vertical heights of the striking point, this paper classifies the height into six categories: 1.6, 1.7, 1.8, 1.9, 2.0, and 2.1. The angles that athletes smash the ball also differ; therefore this paper makes an analysis of spiking from the perspective of striking angle. Afterwards, on the basis of the spiking angle, the position where the ball is hit obliquely into the opponent's court is also studied.

Key words: Analytical hierarchy process; geometric model; moment of inertia; badminton

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INTRODUCTION

There are relatively few domestic studies of badminton. In recent years, research on Chinese badminton has mainly focused on technique, strategy and current condition whereas little attention has been paid to particular action.

According to the book *Brief History of Chinese Badminton's Development*, badminton was brought to some of China's advanced cities around 1910 from European and American countries. Afterwards, Chinese teams have attained great honors in World Badminton Championships and World Cups in badminton.

Nevertheless, the development of badminton in our country has experienced different periods: first being in the lead, then suffering from great sharp fluctuations and finally resting on a relatively high level and making outstanding achievements on the global stage, which is due to our country's vigorous efforts to promote this sport.

2. THE ESTABLISHMENT OF MODELS

2.1 AHP model

2.1.1 Establishing the hierarchical structure model

On the basis of AHP, this paper makes a quantitative analysis of badminton, and establishes three layers: target layer, criteria layer and scheme layer.

The target layer refers to badminton training. The criteria layer refers to influential factors of the scheme, including physical quality c_1, spirit of cooperation c_2, reaction quality c_3 and innovation ability c_4.

The scheme layer incorporates humanities training A_1, physical training A_2 and entertainment training A_3. Then the hierarchical structure is established as Fig.1 shows.

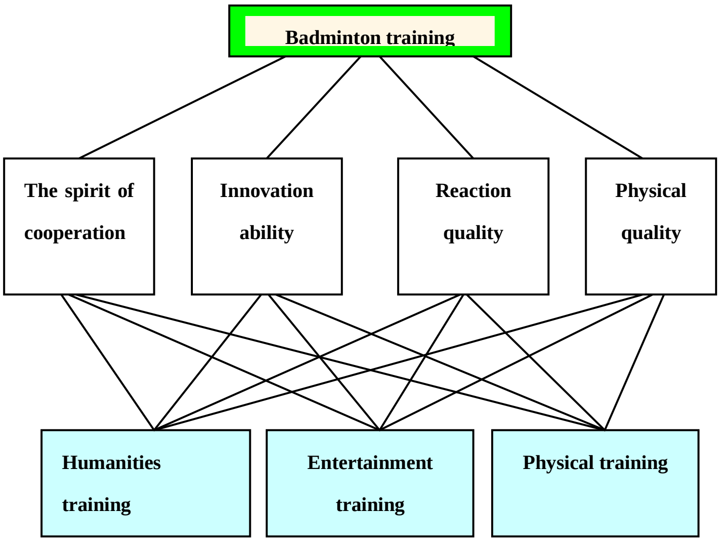


Fig.1: Hierarchical structure

2.1.2 Constructing the judgment (comparison) matrix

The judgment matrix is used to reflect the significance of factors in one layer to those in the above layer in the form of matrix. To make comparison between every two factors and get a quantified judgment matrix, scales from 1 to 9 are introduced as Table 1 demonstrates.

Tab. 1: Scales from 1 to 9

scale a_{ij}	definition
1	i is equally important as j
3	i is relatively more important than j
5	i is more important than j
7	i is much more important than j
9	i is definitely much more important than j
2，4，6，8	the scales of the intermediate states of above descriptions
reciprocal	If i is compared with j, then the judgment value is $a_{ji}=1/a_{ij}$, $a_{ii}=1$

Here is the figure of scales from 1 to 9.

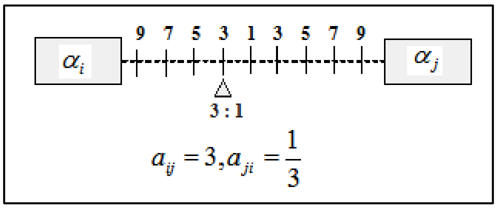


Fig. 2: Scales from 1 to 9

To begin with, the judgment matrix is figured out. Then, according to the above principles and scales from 1 to 9, and with reference to the experience of experts and the author as well as a large quantity of literature, the comparison matrix between every two factors is worked out as Tables 2 to 6 illustrate.

Tab. 2: Comparison matrix

G	c_1	c_2	c_3	c_4
c_1	1	1/3	3	3
c_2	31/8	1	5	5
c_3	1/3	1/5	1	1
c_4	1/3	1/5	1	1

Tab. 3: Comparison matrix

c_1	A_1	A_2	A_3
A_1	1	1	1/3
A_2	1	1	1/3
A_3	3	3	1

Tab. 4: Comparison matrix

c_2	A_1	A_2	A_3
A_1	1	5	5
A_2	1/5	1	5
A_3	1/5	1/5	1

Tab. 5: Comparison matrix

c_3	A_1	A_2	A_3
A_1	1	5	8
A_2	1/5	1	5
A_3	1/8	1/5	1

Tab. 6: Comparison matrix

c_4	A_1	A_2	A_3
A_1	1	5	8
A_2	1/5	1	5
A_3	1/8	1/5	1

2.1.3 Single hierarchical arrangement and its consistency test

A consistency test is carried out with the consistency index $CI = \frac{\lambda_{\max} - n}{n-1}$ in which $\lambda_{\max}$ is the maximum eigenvalue and n is the order of the comparison matrix. The smaller CI is, the closer the judgment matrix reaches complete consistency and vice versa.

2.1.4 Total hierarchical arrangement and its consistency test

$$A=\begin{Bmatrix} 1 & 1/3 & 3 & 3 \\ 3 & 1 & 5 & 5 \\ 1/3 & 1/5 & 1 & 1 \\ 1/3 & 1/5 & 1 & 1 \end{Bmatrix}$$

$$\xrightarrow{\text{normalization of column vectors}}\begin{Bmatrix} 0.214 & 0.192 & 0.3 & 0.3 \\ 0.075 & 0.577 & 0.5 & 0.5 \\ 0.121 & 0.115 & 0.1 & 0.1 \\ 0.201 & 0.115 & 0.1 & 0.1 \end{Bmatrix}$$

$$\xrightarrow{\text{sum by row}}\begin{Bmatrix} 1.066 \\ 2.22 \\ 0.386 \\ 0.386 \end{Bmatrix}$$

$$\xrightarrow{\text{normalization}}\begin{Bmatrix} 0.2515 \\ 0.555 \\ 0.0965 \\ 0.0965 \end{Bmatrix}=\mathrm{W}^{(0)}$$

$$AW^{(0)}=\begin{Bmatrix} 1 & 1/3 & 3 & 3 \\ 3 & 1 & 5 & 5 \\ 1/3 & 1/5 & 1 & 1 \\ 1/3 & 1/5 & 1 & 1 \end{Bmatrix}\begin{Bmatrix} 0.2514 \\ 0.555 \\ 0.0965 \\ 0.0965 \end{Bmatrix}=\begin{Bmatrix} 1.012 \\ 2.275 \\ 0.387 \\ 0.387 \end{Bmatrix}$$

$$\lambda_{\max}^{(0)}=\frac{1}{4}\left(\frac{1.012}{0.251}+\frac{2.275}{0.555}+\frac{0.387}{0.0965}+\frac{0.387}{0.0965}\right)=4.037$$

$$w^{(0)}=\begin{pmatrix} 0.251 \\ 0.555 \\ 0.097 \\ 0.097 \end{pmatrix}$$

The judgment matrix can also be figured out likewise:

$$B_1=\begin{Bmatrix} 1 & 1 & 1/3 \\ 1 & 1 & 1/3 \\ 3 & 3 & 1 \end{Bmatrix}, B_2=\begin{Bmatrix} 1 & 5 & 5 \\ 1/5 & 1 & 5 \\ 1/5 & 1/5 & 1 \end{Bmatrix}, B_3=\begin{Bmatrix} 1 & 5 & 8 \\ 1/5 & 1 & 5 \\ 1/8 & 1/5 & 1 \end{Bmatrix}, B_4=\begin{Bmatrix} 1 & 5 & 8 \\ 1/5 & 1 & 5 \\ 1/8 & 1/5 & 1 \end{Bmatrix}$$

The corresponding maximum eigenvalue and eigenvector are:

$$\lambda^{(1)}{}_{\max}=3.64, \omega^{(1)}{}_1=\begin{Bmatrix} 0.244 \\ 0.244 \\ 0.512 \end{Bmatrix}$$

$$\lambda^{(2)}{}_{\max}=3.29, \omega^{(1)}{}_2=\begin{Bmatrix} 0.657 \\ 0.251 \\ 0.092 \end{Bmatrix}$$

$$\lambda^{(3)}{}_{\max}=3.31, \omega^{(1)}{}_3=\begin{Bmatrix} 0.648 \\ 0.204 \\ 0.148 \end{Bmatrix}$$

$$\lambda^{(4)}{}_{\max}=3.31, \omega^{(1)}{}_4=\begin{Bmatrix} 0.648 \\ 0.204 \\ 0.148 \end{Bmatrix}$$

Consistency indexes are used for a test： $CI = \frac{\lambda_{\max} - n}{n-1}$, $CR = \frac{CI}{RI}$

Tab. 7: The value of RI

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

（1）For judgment matrix A , $\lambda^{(0)}{}_{\max} = 4.073, RI = 0.9$

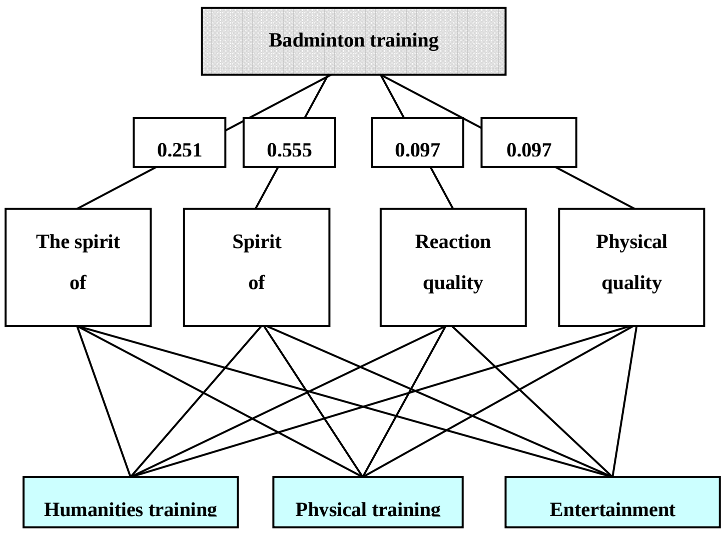
$$CI = \frac{4.073 - 4}{4 - 1} = 0.24$$

$$CR = \frac{CI}{RI} = \frac{0.024}{0.90} = 0.027 < 0.1$$

It means that the inconsistency of A is acceptable, and its eigenvector can be replaced by weight vector.

(2）Similarly, for judgment matrixes B_1, B_2 , B_3 , B_4 , all have passed the consistency test according to the above principle.

Calculation results from the target layer to the scheme layer are illustrated in the hierarchical structure diagram as Fig.3 shows:



$$\begin{Bmatrix} 0.252 \\ 0.089 \\ 0.66 \end{Bmatrix}, \begin{Bmatrix} 0.575 \\ 0.286 \\ 0.139 \end{Bmatrix}, \begin{Bmatrix} 0.624 \\ 0.240 \\ 0.136 \end{Bmatrix}, \begin{Bmatrix} 0.185 \\ 0.240 \\ 0.575 \end{Bmatrix}$$

Fig.3: Hierarchical structure diagram

The calculation structure is shown as follows:

$$\omega^{(1)} = (\omega_1^{(1)}, \omega_2^{(1)}, \omega_3^{(1)}, \omega_3^{(1)})$$

$$= \begin{Bmatrix} 0.624 & 0.185 & 0.252 & 0.575 \\ 0.234 & 0.240 & 0.089 & 0.286 \\ 0.136 & 0.575 & 0.66 & 0.139 \end{Bmatrix}$$

$$w = w^{(1)} w^{(0)}$$
$$= \begin{Bmatrix} 0.252 & 0.575 & 0.624 & 0.185 \\ 0.089 & 0.286 & 0.240 & 0.240 \\ 0.66 & 0.139 & 0.136 & 0.575 \end{Bmatrix} \begin{Bmatrix} 0.567 \\ 0.056 \\ 0.104 \\ 0.273 \end{Bmatrix}$$
$$= \begin{Bmatrix} 0.291 \\ 0.156 \\ 0.553 \end{Bmatrix}$$

This paper concludes that for badminton, humanities training accounts for 44.7% whereas physical training accounts for 55.3%, which demonstrates that badminton is not just a sport of challenging physical limits, but the one which calls for technics, skills and so forth.

2.2 Solution of the spiking trajectory and shot point under the geometric model

A spiking model of badminton is established according to the geometric principle, and its trajectory and shot point are also determined according to the differences of high batting and low batting. As Fig.4 demonstrates:

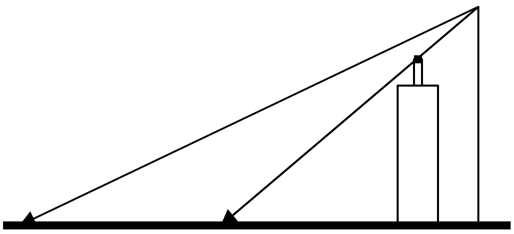


Fig.4

When an athlete spikes, he or she should try to keep the arms straight in front and vertical to the striking point. The higher he or she jumps, the more likely that ball can pass over the net. And the height of the striking point determines the trajectory and landing point of the ball and leads to either long-track ball or short-track ball. Thus, according to different vertical heights of the striking point, this paper classifies the heights into six categories: 1.6, 1.7, 1.8, 1.9, 2.0, and 2.1. Then on the basis of vertical distance between the striking point and the ball net, Table 8 is drawn.

Tab. 8: Landing point of the ball flying over the net at the smallest margin

vertical height/H	1.6	1.7	1.8	1.9	2.0	2.1
the distance between the striking point and the ball net is 0.75m	17.23	9.07	6.15	4.65	3.74	3.12
the distance between the striking point and the ball net is 0.5m	10.55	6.05	4.10	3.10	2.49	2.08
the distance between the striking point and the ball net is 0.25m	5.78	3.02	2.05	1.55	1.25	1.04

As can be seen from Table 8, different distances between the striking point and the net surface contribute to different landing points of badminton. Moreover, different batting heights of athletes can lead to different positions of the ball after it passes over the net.

2.2.1 Improvements of the low-landing ball's spiking trajectory and shot point under the geometric model

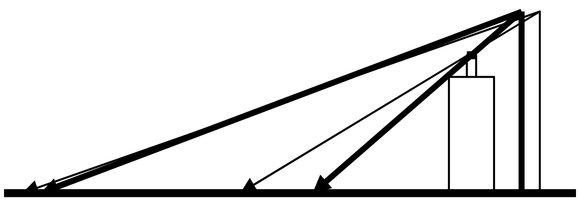


Fig. 5

Similarly, based on the different vertical heights of the striking point, this paper classifies height into six different categories: 1.6, 1.7, 1.8, 1.9, 2.0, and 2.1. Then, according to different vertical distances between the striking point and the net surface, Table 9 is drawn.

Tab. 9: Landing point of the ball flying over the net at the smallest margin after the distance between the striking point and the net surface is reduced to 0.1m

vertical height /H	1.6	1.7	1.8	1.9	2.0	2.1
The distance between the striking point and the net surface is 0.75m	45.16	25.01	12.73	9.45	5.6	3.15
the distance between the striking point and the net surface is 0.5m	6.32	2.89	2.68	2.48	1.57	0.68
the distance between the striking point and the net surface is 0.25m	8.98	6.58	4.08	3.12	2.95	1.68

As can be learned from Table 9 and Figure5, although the distance between the striking point and the net surface has been reduced into 0.1m, the low-batting ball's shot positions in the opponent's court vary greatly

2.2.2 Changing the angle of hitting the ball

The angle of spiking is not vertical, nor is vertical for the ball to be shot to the opponent's court. Generally speaking, when athletes spike, the ball is hit by a certain angle and shot to the opponent's court obliquely.

Suppose that the vertical distance between the striking point and the periphery of the court is 0.5m, when an athlete hits a ball at an angle of 45° on the right, then the distance between the striking point and shot point S is:

$$S = \frac{0.5}{\cos 45^\circ} = \frac{0.5}{\sqrt{2}/2} = 0.7072m$$

Meanwhile, when the angle of spiking is 30° offset, the distance between the shot point and the striking point's projection S is:

$$S = \frac{0.5}{\cos 30} = \frac{0.5}{\sqrt{3}/2} = 0.574m$$

As Fig.6 shows,

Based on the data of Figure 3, Table 10 is established for analysis.

Tab. 10: Landing spots of 6 striking points when the ball passes over the net at the smallest margin

angle	vertical angle	45°	coordinate of landing point $\begin{pmatrix} x \\ y \end{pmatrix}$	30°	coordinate of landing point $\begin{pmatrix} x \\ y \end{pmatrix}$
1.65m	9.45m	12.45m	$\begin{pmatrix} 11.15 \\ 11.15 \end{pmatrix}$	11.47m	$\begin{pmatrix} 11.45 \\ 6.24 \end{pmatrix}$
1.75m	6.14m	8.57m	$\begin{pmatrix} 6.05 \\ 6.05 \end{pmatrix}$	5.68m	$\begin{pmatrix} 6.02 \\ 3.476 \end{pmatrix}$
1.85m	4.2m	5.6m	$\begin{pmatrix} 4.12 \\ 4.12 \end{pmatrix}$	4.75m	$\begin{pmatrix} 4.08 \\ 2.356 \end{pmatrix}$
1.95m	3.15m	4.37m	$\begin{pmatrix} 3.25 \\ 3.25 \end{pmatrix}$	3.64m	$\begin{pmatrix} 3.08 \\ 1.86 \end{pmatrix}$
2.05m	2.49m	3.52m	$\begin{pmatrix} 2.18 \\ 2.18 \end{pmatrix}$	2.89m	$\begin{pmatrix} 2.48 \\ 1.42 \end{pmatrix}$
2.15m	2.11m	2.98m	$\begin{pmatrix} 1.95 \\ 1.95 \end{pmatrix}$	2.41m	$\begin{pmatrix} 2.05 \\ 1.47 \end{pmatrix}$

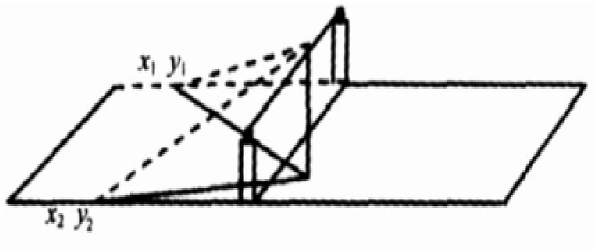


Fig.6: Shot points when angles change

2.3 Calculation of Moment of Inertia of arms when striking a ball

Through the Lagrange equation, this paper gets the restrained particle kinetic equation in which Lagrange function L is the differential value between systematic kinetic energy K and potential energy P :

$$L = K - P$$

The systematic dynamic equation is

$$F_i = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i}\right) \quad i = 1,2,\ldots,n$$

In the above equation, $\dot{q}_i$ is the corresponding speed, q_i is the coordinate of potential energy and kinetic energy, F_i is the force exerted by the i-th coordinate, and the angles between the thigh and lower leg with the axis are θ_1, θ_2, and the lengths are respectively l_1, l_2, and the distances between the gravity position of front and rear arm and the elbow center and knee are p_1, p_2, and the coordinate of the arm's center of gravity (X_1, Y_1) is

$$\begin{cases} X_1 = p_1 \sin\theta_1 \quad Y_1 = p_1 \cos\theta_1 \\ X_2 = l_1 \sin\theta_1 + p_2 \sin(\theta_1 + \theta_2) \quad Y_2 = -l_1 \cos\theta_1 - p_2 \cos(\theta_1 + \theta_2) \end{cases}$$

Similarly, the coordinate of the arm's center of gravity of arms (X_2, Y_2) can be figured out. The systematic kinetic energy E_k and potential energy E_p have the following expressions:

$$\begin{cases} E_k = E_{k1} + E_{k2}, E_{k1} = \frac{1}{2} m_1 p_1^2 \dot{\theta}_1^2 \\ E_{k2} = \frac{1}{2} m_2 l_1^2 \dot{\theta}_1^2 + \frac{1}{2} m_2 p_2^2 \left(\dot{\theta}_1 + \dot{\theta}_2\right)^2 + m_2 l_2 p_2 \left(\dot{\theta}_{01}^2 + \dot{\theta}_1 \dot{\theta}_2\right) \cos\theta_2 \\ E_p = E_{p1} + E_{p2}, E_{p1} = \frac{1}{2} m_1 g p_1 (1 - \cos\theta_1) \\ E_{p2} = m_2 g p_2 [1 - \cos(\theta_1 + \theta_2)] + m_2 g l_1 (1 - \cos\theta_1) \end{cases}$$

The above equation is then expressed in the form of Lagrange function. From the systematic dynamic equation of Lagrange, the torques on the hip joint and knee joint M_h and M_k are also worked out:

$$\begin{bmatrix} M_h \\ M_k \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} \begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \end{bmatrix} + \begin{bmatrix} D_{111} & D_{122} \\ D_{211} & D_{222} \end{bmatrix} \begin{bmatrix} \dot{\theta}_1^2 \\ \dot{\theta}_2^2 \end{bmatrix} + \begin{bmatrix} D_{112} & D_{121} \\ D_{212} & D_{221} \end{bmatrix} \begin{bmatrix} \dot{\theta}_1 \dot{\theta}_2 \\ \dot{\theta}_2 \dot{\theta}_1 \end{bmatrix} + \begin{bmatrix} D_1 \\ D_2 \end{bmatrix}$$

D_{ijk} in the above equation is worked out as

$$D_{111} = 0 \quad D_{222} = 0 \quad D_{121} = 0$$

$$D_{22} = m_2 p_2^2$$

$$D_{11} = m_1 p_1^2 + m_2 p_2^2 + m_2 l_1^2 + 2m_2 l_1 p_2 \cos\theta_2$$

$$D_{12} = m_2 p_2^2 + m_2 l_1 p_2 \cos\theta_2 \quad D_{21} = m_2 p_2^2 + m_1 l_1 p_2 \cos\theta_2$$

$$D_1 = \left(m_1 p_1 + m_2 l_1\right) g \sin\theta_1 + m_2 p_2 g \sin\left(\theta_1 + \theta_2\right)$$

$$D_{122} = -m_2 l_1 p_2 \sin\theta_2$$

$$D_{211} = m_2 l_1 p_2 \sin\theta_2$$

$$D_{112} = -2m_2 l_1 p_2 \sin\theta_2$$

$$D_{212} = D_{122} + D_{211}$$

$$D_2 = m_2 p_2 g \sin\left(\theta_1 + \theta_2\right)$$

With reference to theoretic equations, the mechanical movement on badminton athletes' hand joints is analyzed when they spike. And spiking skills are studied with reference to mechanical analyses of shoulder and elbow joints.

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