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Special quality evaluation and optimal putting angle model for shot putters based on grey correlation analysis

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ABSTRACT

In order to improve the shot putters' competition results, this study establishes the mathematical model of shot sport. By working out the functional relationship between the maximum projectile range and its influencing factors, and conducting analysis of its dynamics and mechanical characteristics, this study obtains the optimal putting angle for shot put. Besides, the results from grey correlation analysis reflect the numerical relationship between athletic performance and each special quality indicator, the contribution of the various indicators to the performance can be calculated and thus the main factors affecting the shot special achievement can be obtained. The results of this study have a positive impact on shot related researches and have great significance in the better and faster development of field and track. What's more, this research provides certain basis for the shot put coaches and athletes in training, encouraging the athletes to go beyond themselves continuously.

KEYWORDS

Grey correlation;
Shot putting;
Optimal putting;
Mathematical model.

INTRODUCTION

Woman Shot has been an advantageous project in China's track and field events. Shot putters' achievements are not only related to their special qualities, but also closely linked to technical movements of the athletes. A variety of qualities of the athletes have impact on the competition results, even a tiny details will also have a role in the playing. The shot putting is a projectile motion. Through specific physical analysis of the movement process of the shot putting, it eventually can be identified as a certain height projectile motion. By finding the functional relationship between the maximum projectile range and its influencing factors, the maximum range can be solved. Therefore, the study of the impact of the shot putter's special quality on the shot competition results, and discussion on the optimal putting angle are of great significance.

Previous studies on shot putters' special qualities are mainly based on analytical hierarchy process, in which the influence of human factors is obvious in the establishment of the judgment matrix. As a result, the final calculated weight of the special quality may be inconsistent with the actual value. In the researches on shot put putting angle, many scholars have calculated the ideal projectile angle of the shot, but the research formulas are all determined under the assumption that

FULL PAPER

the shot initial velocity and players' heights are constant. However, in fact, shot putters' heights and initial shot velocities are variant and the theoretical formula deduced will be in some differences with the actual situation, thus it cannot properly guide the shot put athletes to improve the technical movements.

This study takes into account factors as the shot's initial velocity, the time from shot's releasing to landing, the acceleration of gravity, the shot's releasing angle, the horizontal distance from the shot's releasing point to the landing point and the shot's releasing height, and establishes the optimal putting angle model for shot putting. With the shot scores and indicators of various special quality of a top-notch grade female shot putter as research contents, determine the correlation degree between each special quality indicator and the corresponding competition results based on grey calculation, to provide a certain basis for shot coaches and athletes in training.

OPTIMAL SHOT PUTTING ANGLE MODEL

Symbol Description in optimal shot putting angle model

v_0: Shot's initial velocity
t: The time from shot's releasing to landing
g: Acceleration of gravity
α: Shot's releasing angle
x: The horizontal distance from the shot's releasing point to the landing point
h: Shot's releasing height

Modelling of optimal shot putting angle

According to the characteristics of the putting motion, it can be approximately regarded as projectile motion in the physics. Analyze the shot's motion process, the motion of the shot can be decomposed into two parts: uniform linear motion along the direction of the initial velocity and free falling downward the vertical direction, as shown in Figure 1, Figure 2:

It can be acquired from Figure 2 that:

$$x^2 = (v_0 t)^2 - (\frac{1}{2}gt^2 - h)^2 = -\frac{g^2 t^4}{4} + (v_0^2 + gh)t^2 - h^2 \quad (1)$$

When $t^2 = -\frac{b}{2a} = \frac{2v_0^2 + 2gh}{g^2}$, x^2 has the extreme value, and the maximum value of x is:

$$x_{max} = (v_0 t \cos\alpha)_{max} = \frac{v_0\sqrt{v_0^2 + 2gh}}{g} \quad (2)$$

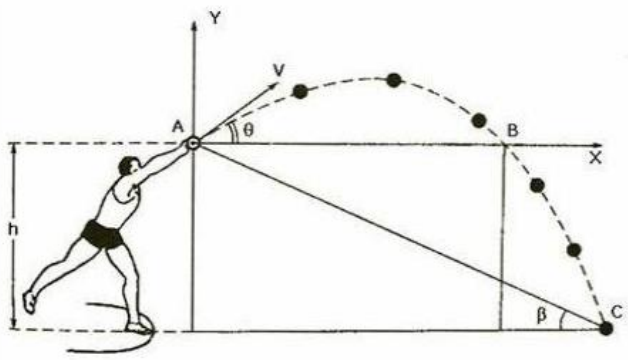

Figure 1 : Schematic diagram of shot putting

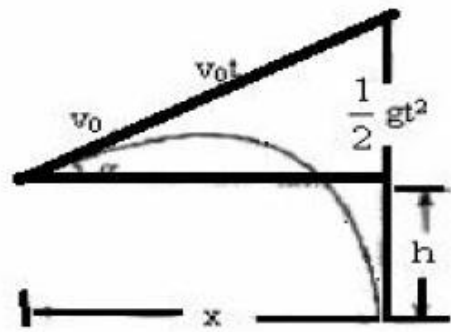

Figure 2 : Schematic diagram of shot motion

In the vertical direction $-h = v_0 t\sin\alpha - \frac{1}{2}gt^2$, substitute t into this equation and then it can be obtained that

$$\alpha = \arcsin\frac{v_0}{\sqrt{2v_0^2 + 2gh}} \quad (3)$$

Judging from the above formula, the optimal putting angle is related to v_0, and h as well, and the value is always below 45°.

According to the projectile motion, it can be drawn that when athletes throw shots, the farthest distance the object can fly depends on the releasing velocity v_0; the shot's releasing angle α and the releasing height h.

(1) Shot releasing height: The shot's releasing height depends on the athlete's height and arm length, as well as the athlete's body and training level. The increasing of releasing height will result in almost the same increase degree of the shot's flight distance. Whereas, each athlete's height, arm length

and the technical level of training are relatively fixed, from which aspects it is undesirable to increase the shot scores.

(2) Shot releasing angle: The best shot angle (38°~42°) is less than 45°, due to that the releasing point is higher than the landing point. If shot releasing height increases, the optimal releasing angle decreases, and vice versa. Shot releasing angle value also depends on the shot releasing velocity; when the shot releasing velocity increases, the optimal value of the shot angle will increase (Dyson, 1968). Deviation from the best shot angle ±3°~ 4°, has little effect on the distance of shot, but if the deviation is about 10°, the flight distance will decrease by 1 m. This shows that the effect of shot releasing angle on the shot's distance is not great and its negative effects can be made up by the releasing velocity.

(3) Shot releasing velocity: Shot flight distance is proportional to the square of the shot releasing velocity. Thus releasing velocity is the most important factor affecting the shot performance. Shot releasing velocity increases by 1 times, the results will be increased by 3 times. Judging from sports practice, shot releasing height and angle of different athletes are relatively constant, and there is no significant change. So it can be seen that to increase shot releasing velocity is the most important way to improve the shot scores.

Mechanical factors influencing shot releasing velocity

Shot releasing velocity depends on the size and orientation, distance and duration of the force acting on the shot, which can be expressed by the following formula:

$$v = \frac{F_t}{m} = \sqrt{\frac{2F_s}{\mathrm{m}}} \quad \textbf{(4)}$$

In the above formula (4): v is the shot releasing velocity, F is the force acting on the shot, t is the duration time of the force, s is the duration distance of the force, m is the mass of the shot. The conditions establishing the formula is that F is constant. The size of the force acting on the shot depends on the athlete's body readiness level and the position of the body in forcing phase; the force effects are reflected by. The mechanical characteristics of the movement depend on the orientation of the body and movement techniques. As the possibility of increasing the distance of the force is restricted due to the putting circle, it becomes very important to increase the force acting on the shot. All changes of shot putting techniques are around the increase of the force or the time of the force acting on the shot (force distance), and changes in the history of the development of shot putting techniques also confirms this point.

Velocity analysis at shot releasing: Shot releasing velocity is the sum of the velocity generated at various stages. Due to the different direction of the velocity vector, the synthesis of the velocity follows the parallelogram law. The standing shot putting distance of world class athletes is about 19-20m and the corresponding releasing velocity is about 13m·s-1. If the athlete is able to conduct mathematical combination (velocity in the same direction) of the two velocity and to complete the shot put action, shot releasing velocity may reach 15-15.5m·s-1 and the corresponding putting distance is 25-26m (Tutevich, 1969; Koltai, 1973). However, due to the lack of linearity of the shot's velocity in slippery stage and final forcing phase, it results in a considerable loss of its initial velocity and final velocity. Koltai (Koltai, 1973) and Kerssenbrok (Kerssenbrok, 1974) reported that the loss of the initial velocity is up to 60% to 70%.

GREY CORRELATION ANALYSIS OF SHOT ATHLETES' SPECIAL QUALITY AND COMPETITION RESULTS

Judge the correlation degree of each indicator and the performance according to the grey correlation and screen effective variables.

Selection of reference series

$$x_0 = \{x_0(k)k = 1,2,...n\} = (x_0(1), x_0(2),...x_0(n)) \quad \textbf{(5)}$$

Wherein, k means the moment. Assume that t there are m comparison series:

$$x_i = \{x_i(k)|k = 1,2,..n\} = (x_i(1), x_i(2)x_i(n)), i = 1,2,...m$$

The initial value processing of the raw data

Ordered series $x = (x(1),\mathrm{x}(2)...\mathrm{x}(\mathrm{n}))$

Mapping relation:

$$f(x(k)) = y(k), k = 1,2,..n \quad \textbf{(6)}$$

Data conversion-the initial value processing of the

series

$$f(x(k)) = \frac{x(k)}{X(1)} = y(k), x(1) \neq 0 \quad (7)$$

Correlation coefficient

The correlation coefficient of comparison series X_i and reference series X_0 in time k:

$$\xi_i(k) = \frac{\min_s \min_t |x_0(t) - x_s(t)| + a \max_s \max_t |x_0(t) - x_s(t)|}{|x_0(k) - x_i(k)| + a \max_s \max_t |x_0(t) - x_s(t)|} \quad (8)$$

a means the resolution coefficient, the greater the resolution coefficient, the greater the resolution is; and vice versa.

Calculation of the correlation degree:

$$r_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \quad (9)$$

The correlation degree of comparison series x_i and x_0 reference seriescan be told from formula (9). Correlation degree is the average of all correlation coefficients at all moments, which collects and processes the excessively dispersed information. Analysis on various issues can be conducted based on the concept of correlation degree.

Solution of the model

From a follow-up survey on certain top-notch grade female shot athlete, the time series data of the best scores and 16 special qualities and physical fitness from 1982-1986 is obtained (TABLE 1). Try factor analysis on the shot putter's special performance, and conduct initialization processing of each series in TABLE 1.

In general, different series in the practical problems often have different dimensions, whereas, the calculation of the correlation coefficients requires the dimension to be the same. Therefore, firstly the variety of data should be dimensionless. Moreover, with the purpose of easy comparison, all the series are required to have a common intersection. In order to solve these two problems, conduct the transformation of the given series. A given sequence x = (x (1), x (2), x (n)), then:

$$\bar{x} = \left(1, \frac{x(2)}{x(1)}, \frac{x(3)}{x(1)} \cdots \frac{x(n)}{x(1)}\right) \quad (10)$$

The above is the initialization sequence for the original series. Conduct initialization processing of the 17 series in TABLE 2. For the former 15 series, as time increases, the increase in the value means the progress of athletic level; while for the latter 2 series, as time increases, the decrease in the value (in seconds) means the progress of athletic level. Therefore, in the initialization processing of series x_{15} x_{15}, adopt the following formula:

$$x_i = \left(1, \frac{x_i(1)}{x_i(2)}, \frac{x_i(1)}{x_i(3)}, \frac{x_i(1)}{x_i(4)}, \frac{x_i(1)}{x_i(5)}\right), i = 15,16 \quad (11)$$

TABLE 1 : A top-notch grade female shot athlete's data (1982-1986)

Each quality	1982	1983	1984	1985	1986
Shot Special achievements x_0	13.6	14.01	14.54	15.64	15.69
4kg Front putting x_1	11.5	13	15.15	15.3	15.02
4kg Back putting X_2	13.76	16.36	16.9	16.56	17.3
4kg Standing putting x_3	12.41	12.7	13.96	14.04	13.46
Standing long jump X_4	2.48	2.49	2.56	2.64	2.59
Power clean x_5	85	85	90	100	105
Snatch x_6	55	65	75	80	80
Bench press X_7	65	70	75	85	90
3kg Front putting x_8	12.8	15.3	16.24	16.4	17.05
3kg Back putting X_9	15.3	18.4	18.75	17.95	19.3
3kg Standing putting x_{10}	12.71	14.5	14.66	15.88	15.7
3kg Glissade X_{11}	14.78	15.54	16.03	16.87	17.82
Standing triple jump x_{12}	7.64	7.56	7.76	7.54	7.7
Full squat X_{13}	120	125	130	140	140
Clean and jerk x_{14}	80	85	90	90	95
30 meters running x_{15}	4.02	4.25	4.01	4.06	3.99
100 meters X_{16}	13.01	13.42	12.85	12.72	12.56

The selection of reference series

The shot special achievements, i.e. seriesare x_0 selected as the reference series.

Solving correlation degree

In accordance with the requirements of the problem, naturally select shot putters' special achievements as reference series. The initialized series of all series in TABLE 2 are substituted into formula (1) and (2), and the calculated correlation degrees of all series are shown in TABLE 3.

Judging from TABLE 3, the eight key factors impacting the shot special achievements are full squat, 3kg

FULL PAPER

glissade, power clean, 4kg standing putting, clean and jerk, standing long jump, 30 meters jump and 100 meters jump achievements. Therefore, the training should focus on to consider arrangements for the practice of the eight indicators. This can reduce the blindness of training and improve training efficiency.

TABLE 2 : The data after initialization

Each quality	1982	1983	1984	1985	1986
Shot Special achievements x_0	1.00	1.03	1.07	1.15	1.15
4kg Front putting x_1	1.00	1.13	1.32	1.33	1.31
4kg Back putting x_2	1.00	1.19	1.23	1.20	1.26
4kg Standing putting x_3	1.00	1.02	1.12	1.13	1.08
Standing long jump x_4	1.00	1.00	1.03	1.06	1.04
Power clean x_5	1.00	1.00	1.06	1.18	1.24
Snatch x_6	1.00	1.18	1.36	1.45	1.45
Bench press x_7	1.00	1.08	1.15	1.31	1.38
3kg Front putting x_8	1.00	1.20	1.27	1.28	1.33
3kg Back putting x_9	1.00	1.20	1.23	1.17	1.26
3kg Standing putting x_{10}	1.00	1.14	1.15	1.25	1.24
3kg Glissade x_{11}	1.00	1.05	1.08	1.14	1.21
Standing triple jump x_{12}	1.00	0.99	1.02	0.99	1.01
Full squat x_{13}	1.00	1.04	1.08	1.17	1.17
Clean and jerk x_{14}	1.00	1.06	1.13	1.13	1.19
30 meters running x_{15}	1.00	0.95	1.00	0.99	1.01
100 meters x_{16}	1.00	0.97	1.01	1.02	1.04

TABLE 3 : The correlation degrees of all series

r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8
0.588	0.663	0.854	0.776	0.855	0.502	0.659	0.582
r_9	r_{10}	r_{11}	r_{12}	r_{13}	r_{14}	r_{15}	r_{16}
0.683	0.696	0.896	0.705	0.933	0.847	0.745	0.726

CONCLUSIONS

The key factor of shot put techniques is shot releasing velocity, so the each aspect in shot put training should be focused on improving the releasing velocity. Human biological and functional differences result in that the optimal shot releasing angles for different athletes are quite different. Therefore, it should avoid blindly to pursue and to imitate the best angle of a fixed value, which leads to the unnecessary loss of velocity and affects the results of the shot put. At the premise of not affecting the shot releasing velocity, according to the actual situation of the athletes, identification of the appropriate shot releasing angle is the basis of scientific training.

Each project in field and track events has a number of quantitative indicators and the sport possesses strong grey property. This study applies grey correlation analysis method to reflect the numerical relationship between the competition results and each indicator and works out the contribution of the various indicators to the achievement. And then obtain the main factors affecting the shot special performance, which are accordingly shot back putting> shot front putting> standing triple jump> standing long jump> bench and press> clean and jerk> squat > snatch> 100m> 30m. Adopt grey correlation degree to judge the correlation degree of each indicator and the achievement and then select the effective variables. Grey correlation degree method makes up for the shortcomings of mathematical statistical methods for system analysis and applies equally whatever sample size and sample law. What's more, this method has small amount of calculations and it is simple, the situation that the quantitative results are different with the qualitative analysis results are not likely to occur. And it has unique advantages in the field of quantitative analysis and evaluation of non-linear, discrete, and dynamic data. According to the degree of similarity of the sequence curve geometry, it judges and intends to overcome the limitations of regression analysis in system analysis. The results of this study are expected to have a positive impact on relative researches, and great significance for the better and faster development of athletics and encouraging the athletes to go beyond themselves continuously.

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