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Research on the impact of physical characteristics on the best shot angle based on curve fitting

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ABSTRACT

This paper uses the projectile motion principles of biomechanics, establishes the mathematical model of shot throwing, and obtains the three factors affecting the shot throwing distance: shot speed, shot angle and shot height of the shot, and conducts preliminary qualitative analysis on them. It then re-uses gray correlation analysis to discuss the impact of three factors on the throwing distance during the throwing process, and uses the fitting way to get the fitting formula of shot speed and shot angle. Finally it arrives at the quantitative relationship between them, and the ideal shot angle of the shot throwing is around 36 °.

KEYWORDS

Shot put;
Gray correlation analysis;
Curve fitting;
Physical characteristics.

INTRODUCTION

Shot is a major throwing event of track and field athletics; the throwing distance is the only standard to measure an athlete's performance, and the problem that the athletes and coaches are most concerned about. By the biomechanical theory, there are three factors that affect throwing distance: the initial velocity of the shot when shooting out of the hand, the shot angle and shot height. So far, more phenomenon appear that use the kinematics knowledge in physics to study the shot throwing motion, few studies consider the impact of the shot height. In the vast research, literature and textbooks at home and abroad the obtained best shot angle is mostly about 42 °, but the actual data shows that the best shot angle of elite athletes is often lower than 42 °, i.e., theory and practice conflicts with each other.

In this study, based on a data set of excellent Shot Putters, through the establishment of gray correlation analysis model, it obtains the impact size of the initial throwing velocity, shot angle and shot height three factors on the throwing distance that is the sensitivity. According to this and by combining with the actual situation, it uses curve fitting method to obtain the best shot angle of elite athletes, which corrects the erroneous theory all along, and provides some guidance to the shot-putter.

THE MECHANICS MODEL OF SHOT PUT THROWING SPORT

Conduct mechanical analysis on the throwing process of the shot; because the process is a more complex dynamic process, there are some uncertain factors; in order to facilitate the mathematical analysis and data processing, we have the following two hypothesis:

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① the shot put is regarded as a particle; ② the air resistance is very small compared to the mass of the shot, so air resistance is ignored.

First, took the position of shot point as the origin, the horizontal throwing direction as the positive direction of x-axis and the positive upward direction as the positive direction of the y-axis to establish a coordinate system of shot put throwing motion, shown as Figure 1.

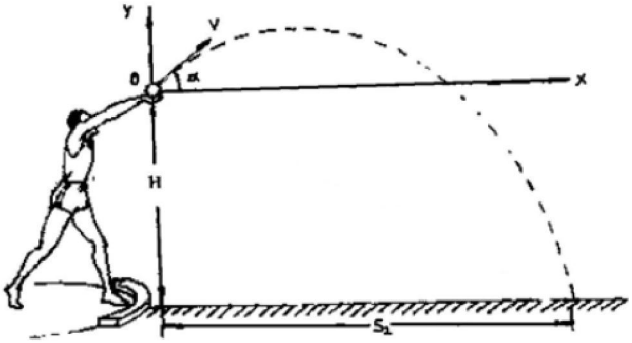

Figure 1 : Schematic diagram of shot put throwing motion

The time of Shot from the shot point to the highest point: $t_1 = \frac{v\sin\alpha}{g}$

The vertical distance from the highest point to the shot point: $h' = \frac{v^2\sin^2\alpha}{2g}$

The time of Shot from the highest point to the landing point: $t_2 = \sqrt{\frac{2(h'+H)}{g}}$

The horizontal distance from the shot point to the landing point: $S_2 = v\cos\alpha\cdot(t_1+t_2)$

So the throwing distance of the shot is:

$$L = S_1 + S_2 = S_1 + \frac{v\cos\alpha}{g}(\sqrt{v^2\sin^2\alpha + 2gH} + v\sin\alpha)$$

Wherein t_1 is the time of shot from the shot point to the highest point, t_2 is the time of Shot from the highest point to the landing point, S_1 is the horizontal distance between the edge of throwing circle to the shot point, S_2 is the horizontal distance between the shot point to the landing point, v is the shot speed of the shot, α is the shot angle of the shot, H is the shot height of the shot. Since the actual throwing distance of the shot is S_2, so this paper takes $L = S_2$.

If v, α and H are independent of each other, that is the change of one factor will not cause the change in another factor; then use the control variable method to obtain the best shot angle:

$$\alpha = \arcsin\frac{v}{\sqrt{2(v^2+gH)}}$$

In accordance with the general characteristic parameters of Shot athletes, take $v = 14\text{m/s}$, $H = 2.00\text{m}$, obtain that the optimal shot angle is $\alpha = 42.3°$, thus the best shot angle of shot is about $42°$.

The practice shows that the shot angle of elite athletes is generally low, through theoretical analysis the reasons are as follows. In general parabolic motion, parabolic body's initial velocity, the angle between the horizontal plane and the initial height is determined by different conditions, namely these factors do not affect each other, which is independent of each other. The throwing process of shot put is happening in and controlled by the same object, namely the human body; and they are inseparable in the whole throwing process, there are certain mathematical function. Thus we cannot use the control variable method, which assumes two variables are known and seek another variable's extremes.

RELATED FACTORS ANALYSIS BASED ON GRAY CORRELATION DEGREE

Grey system theory puts forward the concept of conducting gray correlation analysis on each subsystem, and intends to seek the numerical relationship between the subsystems (or factors) through certain methods . Therefore, the gray correlation analysis provides quantitative measurement for the development change trend of the system, which is ideal for dynamic course analysis.

Take the data of shot-put throwing distance in TABLE 1 as a reference sequence, which is denoted as X_0; take the data sequence of shot speed, shot angle and shot height as compare columns, which is respectively denoted by X_1, X_2, X_3. First, carry through the

initial treatment to the data in TABLE 1, obtain the dimensionless sequence X_0', X_1' X_2' and X_3'. $X_i' = \frac{X_i}{X_i(1)}(i = 0,1,2,3)$, Calculate the correlation coefficient of X_1', X_2', X_3' to X_0', and the calculation formula is as follows:

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

TABLE 1: Shot data of an outstanding Chinese female shot-putter

Shot speed v (m/s)	Shot angle α (°)	Shot height H (m)	Throwing distance L (m)
13.51	38.69	2.00	20.30
14.08	35.13	1.95	21.76
13.82	30.80	2.10	20.49
13.40	36.02	2.11	20.24
13.77	34.64	2.01	20.84
13.41	38.74	1.92	20.02
13.56	35.33	1.77	20.10
14.08	34.60	1.89	21.58
13.23	39.13	2.10	19.84
13.35	34.08	1.89	19.26
13.09	39.93	2.05	19.50
13.86	39.18	1.85	19.83
13.07	39.68	1.97	19.17
13.39	34.14	1.83	19.62
13.30	37.74	1.76	19.76
13.58	37.75	2.02	20.76
13.95	39.06	2.04	21.66
13.59	36.13	1.88	20.40
13.45	38.15	2.06	20.43
13.76	34.38	1.97	20.90
13.58	37.75	2.02	20.78
13.48	40.56	2.00	20.33
13.39	34.67	2.01	19.85
13.35	38.27	1.91	19.81
13.37	36.98	1.95	19.62
13.46	38.68	1.83	19.59
13.20	42.48	1.98	19.58
13.18	38.62	1.89	19.36
13.21	41.32	2.03	19.82
13.38	36.10	1.94	19.71

Where in $\rho \in [0,1]$ is the distinguished coefficient, here we take $\rho = 0.5$, substitute the data it and obtain:

$$\begin{cases} \xi_1 = 0.8846 \\ \xi_2 = 0.6710 \\ \xi_3 = 0.7678 \end{cases}$$

Thus, the biggest factor affecting the shot put throwing distance is the shot speed, followed by shot height, lastly the shot angle; but since the correlation coefficient between the shot angle and the throwing distance is more than 0.6, we cannot ignore its impact. Therefore, in order to improve the shot performance i.e. throwing distance, you should first improve the shot speed, followed by selection of taller athletes; we do not need over-exercise the shot angle when throwing shot. But on the other hand, for highly trained athletes, when he pushes the ball the shot speed and shot height tends to a steady state; if we want to improve the throwing distance at this time, we must choose the best shot angle.

SOLVING THE BEST SHOT ANGLE

45 ° angle is generally considered as the best shot angle, but in fact due to the impact of the shot height, in order to get the furthest throwing distance the required best shot angle needs to be less than 45 °. In the 1995 World Championships, Bartonietz had measured the competition data of shot put; the results show that the final nine players' shot angle deviates 45 °. When throwing, the formation of best shot angle is not a conscious act, it is positively associated with the sliding and the correct prepare action and postures of shot throwing, and the shot speed and shot angle also shows mutual inter-constraint relations. In 1997, when Li Mei Xia et al analyzed the parameters of the World-class Elite Shot Putters, they established a regression equation of shot angle and shot speed:

$$v = 19.45 - 0.152\alpha$$

And the shot angle of elite athletes is $37° \sim 39°$. Using this formula, calculate the best shot angle of the athletes based on the data in TABLE 1. As the athlete's shot height ranges between 1.76 ~ 2.11m, the formula does not consider the impact of the shot height; by calculating the best shot angle and comparing it with the

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TABLE 2 : Piecewise fitting formula and the formula data of Li Mei Xia et al

Shot height (m)	Shot angle (°)	Shot speed (m/s)	Piecewise fitting formula	Li Mei Xia formula
1.76	37.74	13.30	13.60	13.71
1.77	35.33	13.56	13.62	14.08
1.83	38.68	13.46	13.54	13.57
1.83	34.14	13.39	13.56	14.26
1.85	39.18	13.86	13.50	13.49
1.88	36.13	13.59	13.64	13.96
1.89	34.60	14.08	13.59	14.19
1.89	38.62	13.18	13.55	13.58
1.89	34.08	13.35	13.56	14.27
1.91	38.27	13.35	13.57	13.63
1.92	38.74	13.41	13.54	13.56
1.94	36.10	13.38	13.64	13.96
1.95	35.13	14.08	13.62	14.11
1.95	36.98	13.37	13.63	13.83
1.97	39.68	13.07	13.44	13.42
1.97	34.38	13.76	13.58	14.22
1.98	42.48	13.20	12.99	12.99
2.00	38.69	13.51	13.54	13.57
2.00	40.56	13.48	13.33	13.28
2.01	34.64	13.77	13.59	14.18
2.01	34.67	13.39	13.60	14.18
2.02	37.75	13.58	13.60	13.71
2.02	37.75	13.58	13.60	13.71
2.03	41.32	13.21	13.21	13.17
2.04	39.06	13.95	13.51	13.51
2.05	39.93	13.09	13.41	13.38
2.06	38.15	13.45	13.58	13.65
2.10	39.13	13.23	13.50	13.50
2.10	30.80	13.82	13.14	14.77
2.11	36.02	13.40	13.64	13.97

actual shot angle, the equation fitting effect for the data of shot height in the 1.76 ~ 1.99m is not good; but the fitting effect for data between 2.00 ~ 2.11m is better, as shown in TABLE 2. In order to get a more accurate fitting formula, this paper uses curve fitting method, due to the existence of special circumstances, it respectively extracts some data within two height segments of 1.76 ~ 1.99m and 2.00 ~ 2.11m to conduct fitting, and obtain a group of ideal fitting formula.

Use Matlab software to conduct data fitting, the fitting Figure is shown in Figure 2.

And obtain the following formula:

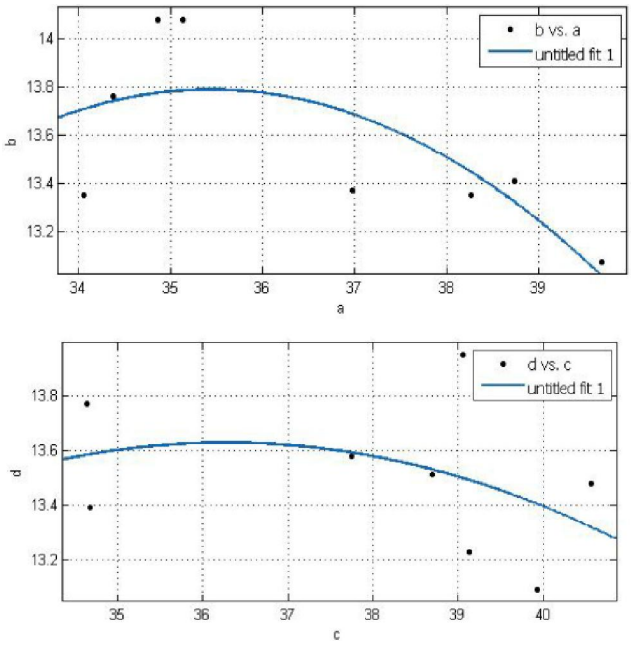

Figure 2 : Data fitting results

$$v = -0.04307\alpha^2 + 3.052\alpha - 40.29 \text{ , } H \in [1.76,1.99]$$

$$v = -0.01676\alpha^2 + 1.216\alpha - 8.418 \text{ , } H \in [2.00,2.11]$$

TABLE 2 is the piecewise fitting formula and the formula data of Li Mei Xia et al, we can see that the piecewise fitting can better reflect the relationship between shot speed and shot angle, and provide an ideal theoretical basis to better improve athletic performance. Meanwhile according to the formula, obtain the opti-

TABLE 3 : Shot achievements and shot angle of world-class outstanding athletes

Name	Achievement (m)	Shot angle (°)
	20.3	38.69
Li Mei Su	20.95	37
	21.76	35.13
	21.52	36.9
Slupianek	22.45	36
	21.28	41.3
	21.41	40
Gunther	22.23	35.5
Timmerman	21.35	35.8
	20.76	37.75
Huang Zhi Hong	21.28	41.3
	21.52	36.9
Ni Muji	21.21	36.7
Cam Bo Noons	21.22	37
Fibingerova	20.86	36
Bayer	21.02	34.1

mum angle shot: $\alpha = \begin{cases} 35.4307, H \in 1.76 \sim 1.99 \\ 36.2768, H \in 2.00 \sim 2.11 \end{cases}$

TABLE 3 shows the world-class elite athletes' shot scores and shot angle; we can see that the optimal shot angle of the athletes is around 36 °, which is consistent with the best angle. The practice proved that, when the shot put goes to the final exertion stage, the body's legs are wide open; due to the structural features of the human body, to push the ball with low angle is in favor of the body muscles to exert greater synergies, more force is applied to the shot and the shot speed is improved; moreover the impact of shot speed on throwing distance is greater than the other two factors, thus the throwing distance is greatly improved.

CONCLUSIONS

By mechanics analysis of the shot throwing process, it obtains the factors that affect the throwing distance,, and. Through the gray correlation analysis it carries through the correlation calculation on the three factors, and obtains the specific relationship of the effect size. Finally, through the shot data analysis and curve fitting of the actual Elite Shot Putters, it obtains the solving equations of optimum shot angle. Based on the above results, it may be discussed as follows: the impact of shot speed on throwing distance is greater than the impact of shot height and shot angle; but the gray correlation between the three and the throwing distance are all greater than 0.6, these three aspects cannot be ignored in the training. Shot speed, shot height and shot angle are not independent of each other, and are inter-constrained, so these two factors should be considered when training the athletes. For the effect of shot height on the throwing distance, it can be controlled by selecting athletes with higher height as much as possible; because its impact on the throwing distance is relatively small, control on the height is not too restrictive. Strengthening the training of the shot speed and explosive power helps to increase the shot throwing distance.

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