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COMPUTER SIMULATION AND MODELING OF SHOT PUTTING PROJECT IN TRACK AND FIELD EVENTS

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ABSTRACT

Shot putting is an important component of track and field events and the throwing distance (s, m) is the greatest concern of coaches and athletes. There are mainly three major factors affecting throwing distance: the initial velocity (v, m/s), release angle (A, °) and release height (h, m) in shot push. So far, it is common to use the physical kinematics knowledge in the research of shot putting, but the release height's impact on the throwing distance is rarely considered. By mathematical modeling and computer simulation, this article analyzes the relation between the three factors (v, A, h) with the throwing distance (s) and determine the best release angle with regard to different release velocity. In addition, the impact of release velocity and release angle on throwing scores is discussed. This article is of certain theoretical guiding significance for athletes and coaches in the selection, training and competition for athletes.

Keywords: *Shot Putting, Throwing Distance, Release Angle, Sensitivity*

1. INTRODUCTION

In shot putting race, athletes (male) are required to throw the shot (weight, 7.265kg) in a 34.92° sartorial area from a circle (d, 2,135m), as shown in Figure 1[1-3]. The observation of athletes' video show that their release angles change greatly, which ranges from $38^0 - 45^0$. And some is as high as 55^0 [1-6]. Then how to achieve a farther throwing distance? Aiming at to realize the farthest throwing distance, the indexes as the shot's release height, residence time in the air and the shot's velocity in horizontal direction are needed. The residence time in the air after the shot-put can be divided into two parts: the first phase is the upward accelerated movement in the vertical direction after shot-put; the second phase is the downward free falling to the grounding [7-10]. This study builds a model, discussing the following questions:

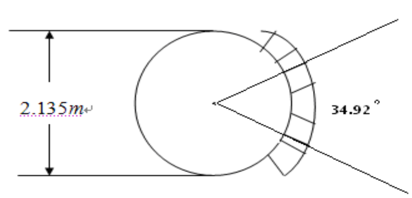

Figure 1: The area of shot putting

Build a mathematical model for shot putting, with release velocity, release angle and release height as parameters [1].

Based on the model, determine the best release angle under different release velocity, with a constant release height. Compare the throwing results' sensitivity to release angle and release velocity.

2. MODEL HYPOTHESIS

The height of athlete (h) and shot-put release velocity (v) are fixed. The shot reaches the maximum height at t_1 after the shot-put. At t_2 after the shot-put, the shot falls to the ground with an acceleration of gravity of $g = 9.8m/s^2$. The angle between the release velocity and horizontal direction is θ , $(0 \le \theta \le 90°)$ (the release angle), the distance between the shot's drop location and the athlete is the throwing distance S [11-14].

As air resistance has little impact on the shot's movement, the influence is ignored.

3. SYMBOL DEFINITION

h : The height of the athlete, assuming as 1.7m;

v : The release velocity of shot putting;

θ : The angle between release velocity and horizontal direction;

S : The distance between shot drop location and the athlete;

g : Acceleration of gravity $g = 9.8m/s^2$;

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t_1: At t_1 after shot-put, the shot reaches the maximum height;

t_2: At t_2 after shot-put, the shot falls to the ground.

4. MODELING AND SOLVING

4.1. Shot motion trajectory graphic

After the shot-put, the trajectory of the shot's motion is shown in Figure 2.

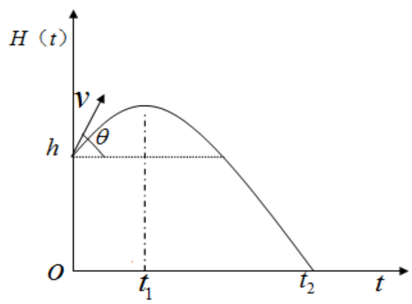

Figure 2: Shot motion trajectory graphic

4.2. The throwing distance S can be determined through the shot motion trajectory

From the simulated shot motion trajectory graphic, at t_1, the shot reaches to the highest height and the velocity at the vertical direction is 0.

$\therefore v\sin\theta = gt_1$, I.E. $t_1 = \dfrac{v\sin\theta}{g}$

∴the maximum height:

$$H(t_1) = h + \frac{1}{2}gt_1{}^2 = h + \frac{v^2\sin^2\theta}{2g}$$

Then establish the parabolic equation:

$$H(t) = a(t - \frac{v\sin\theta}{g})^2 + h + \frac{v^2\sin^2\theta}{2g}$$

$$\because H(0) = a\frac{v^2\sin^2\theta}{g^2} + h + \frac{v^2\sin^2\theta}{2g} = h$$

$$\therefore a = -\frac{g}{2}$$

$$\therefore H(t) = -\frac{g}{2}(t - \frac{v\sin\theta}{g})^2 + h + \frac{v^2\sin^2\theta}{2g}$$

$$H(t_2) = 0$$

$$\therefore t_2 = \sqrt{\frac{2h}{g} + \frac{v^2\sin^2\theta}{g^2}} + \frac{v\sin\theta}{g}$$

$$\therefore S = v\cos t_2$$

The distance between the droop location and the athlete under a constant release height can be determined:

$$S = \sqrt{\frac{2hv^2\cos^2\theta}{g} + (\frac{v^2\sin 2\theta}{2g})^2} + \frac{v^2\sin 2\theta}{2g}$$

4.3. The solving of θ corresponding to the largest S

Judging from the ultimate equation of S, the throwing distance for a athlete with certain ability (the release velocity), is only related to the release angle θ. To determine whether there is a maximum S, is to analyze that whether the functional expression of S on θ possesses the maximum value (as $S \geq 0$ and the discussion of minimum value is meaningless, there is an extremism value of S and it is the maximum value).

Formula: $\dfrac{dS}{d\theta} = 0 \Leftrightarrow S' = 0$

$$S' = \frac{1}{2}\cdot\frac{\frac{2hv^2}{g}\cdot 2\cos\theta(-\sin\theta) + \frac{v^2}{g}\sin 2\theta\cdot\frac{v^2\cos 2\theta}{g}}{\sqrt{\frac{2hv^2\cos^2\theta}{g} + \left(\frac{v^2\sin 2\theta}{2g}\right)^2}} + \frac{v^2\cos 2\theta}{g}$$

$$= \frac{\frac{v^4}{g^2}\sin 2\theta\cos 2\theta - \frac{2hv^2}{g}\sin 2\theta}{\frac{1}{g}\sqrt{8ghv^2\cos^2\theta + v^4\sin^2 2\theta}} + \frac{v^2\cos 2\theta}{g}$$

$$= \frac{v^2}{g\sqrt{8ghv^2\cos^2\theta + v^4\sin^2 2\theta}}(v^2\sin 2\theta\cos 2\theta - 2gh\sin 2\theta + \cos 2\theta\sqrt{8ghv^2\cos^2\theta + v^4\sin^2 2\theta})$$

$$= 0$$

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i.e.:

$$v^2 \sin 2\theta \cos 2\theta + \cos 2\theta \sqrt{8ghv^2 \cos^2 \theta + v^4 \sin^2 2\theta} - 2gh \sin 2\theta = 0$$

$$\Rightarrow (2gh \tan 2\theta - v^2 \sin 2\theta)^2 = 8ghv^2 \cos^2 \theta + v^4 \sin^2 2\theta$$

$$\Rightarrow 4g^2h^2 \tan^2 2\theta - 4ghv^2 \tan 2\theta \sin 2\theta = 8ghv^2 \cos^2 \theta$$

$$\Rightarrow gh \tan^2 2\theta - v^2 \tan 2\theta \sin 2\theta = 2v^2 \cos^2 \theta$$

$$\Rightarrow gh \sin^2 2\theta - v^2 \sin^2 2\theta \cos 2\theta = v^2 (\cos 2\theta + 1) \cos^2 2\theta$$

$$\Rightarrow gh \sin^2 2\theta = v^2 [(1 - \cos^2 2\theta) \cos 2\theta + \cos^2 2\theta + \cos^3 2\theta]$$

$$\Rightarrow gh(1 - \cos^2 2\theta) = v^2 (1 + \cos 2\theta) \cos 2\theta$$

$$\Rightarrow gh(1 - \cos 2\theta) = v^2 \cos 2\theta$$

$$\Rightarrow \cos 2\theta = \frac{gh}{gh + v^2}$$

Then:

When $\theta = \frac{1}{2} \arccos \frac{gh}{gh + v^2}$, the throwing distance is the farthest.

4.4. The function of θ corresponding to v in modeling result figure

According to $\theta = \frac{1}{2} \arccos \frac{gh}{gh + v^2}$, the functional image of v corresponding to θ is shown in Figure 3.

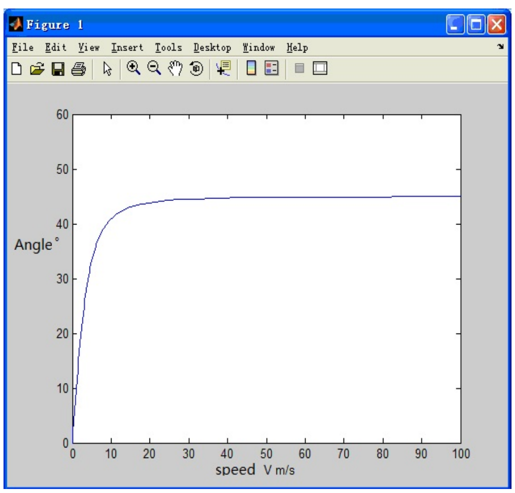

Figure 3: The corresponding angle to the largest release velocity with different velocity

As can be seen from Figure 3, the best release angle differs when the release velocity changes. And the best release angle tends to be 45° as the velocity increases continuously.

4.5. The computer simulation of shot putting distance' sensitivity to the release velocity and release angle

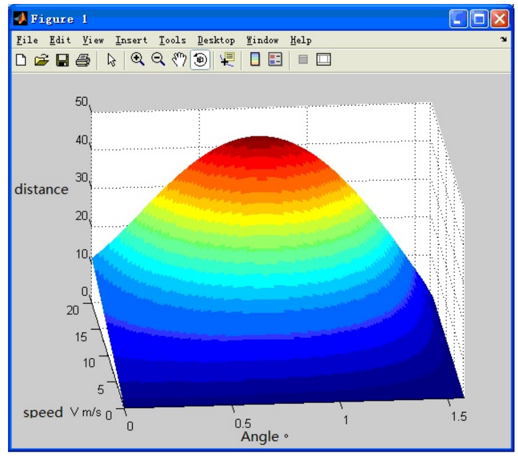

Figure 4: The throwing distance under different velocity and angle

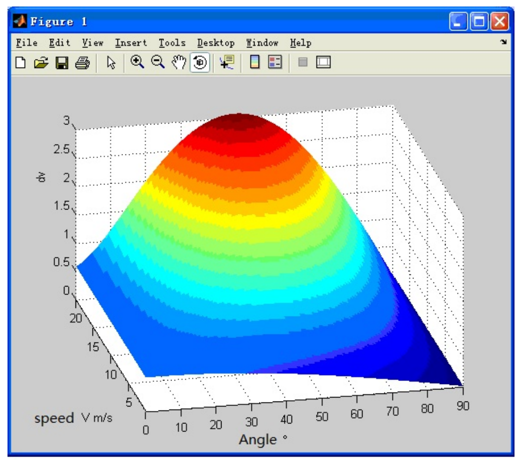

Figure 5: The derivation of S to V under different velocity and angle

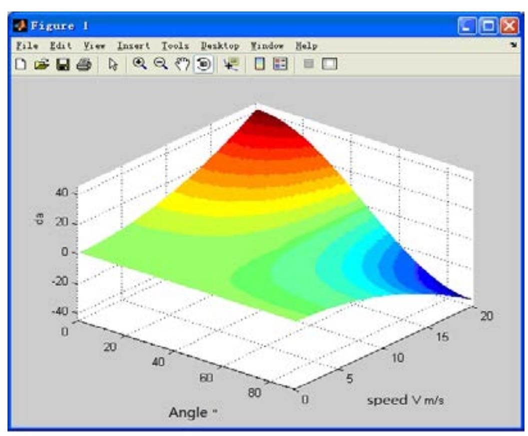

Figure 6: the derivation of S to the release angle under different velocity and angle

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Judging from the above three figures (Figure 4, Figure 5, Figure 6.), it is apparently to determine the shot putting distance' sensitivity to the release velocity and release angle. The influence of release velocity v and release angle A on the throwing distance can be told from the figures, which has certain theoretical guiding significance for the athletes and coaches in the further training and completion.

By means of Excel software, the calculated throwing distance under different release angle when the release velocity ranges from12m/s to 15m/s (supposing that the release height h=2m) is shown in Table 1.

Table 1: The throwing distance when the release velocity ranges from 12m/s to 15m/s

Release angle(°)	Range of release velocity	The maximum throwing distance(m)	The minimum throwing distance(m)	The distance gap(m)	Deviation from the maximum distance（%）	Deviation from the minimum distance（%）
30	12m/s-15m/s	22.8875	15.5560	7.3315	32.03275	47.1297
35	12m/s-15m/s	24.1251	16.2349	7.8902	32.70533	48.6002
40	12m/s-15m/s	24.7834	16.5537	8.2297	33.2066	49.7154
42	12m/s-15m/s	24.8721	16.5722	8.2999	33.37033	50.0833
42.1	12m/s-15m/s	24.8739	16.5715	8.3024	33.37805	50.1007
42.2	12m/s-15m/s	24.8754	16.5705	8.3048	33.38572	50.1180
42.3	12m/s-15m/s	24.8766	16.5695	8.3071	33.39335	50.1352
42.4	12m/s-15m/s	24.8776	16.5682	8.3093	33.40094	50.1523
42.5	12m/s-15m/s	24.8783	16.5668	8.3115	33.40848	50.1693
45	12m/s-15m/s	24.8114	16.4787	8.3327	33.58413	50.5664
50	12m/s-15m/s	24.1845	15.9930	8.1916	33.87111	51.2198

As can be seen from Figure 1: under different release angle, the throwing distance gap is huge when the release velocity ranges in 12m/s-15m/s, about 7m-8m, 32%-34% of the maximum throwing distance and 47%-52% of the minimum throwing distance.

By means of Excel software, the calculated throwing distance under different release velocity when the release angle ranges from42° to 42.5° (supposing that the release height h=2m) is shown in Table 2.

Table 2: The throwing distance when the release angle ranges from 42°to 42.5°

Release velocity(°)	Range of release angle	The maximum throwing distance(m)	The minimum throwing distance(m)	The distance gap(m)	Deviation from the maximum distance（%）	Deviation from the minimum distance（%）
12	42°-42.5°	16.5283	16.52351	0.004794	0.029005	0.029013
12.5	42°-42.5°	17.78721	17.78406	0.003148	0.017695	0.017699
13	42°-42.5°	19.09559	19.0941	0.001488	0.007793	0.007794
13.2	42°-42.5°	19.63299	19.63201	0.000981	0.004995	0.004995
13.4	42°-42.5°	20.17845	20.17775	0.000698	0.003462	0.003462
13.6	42°-42.5°	20.73196	20.73078	0.001181	0.005698	0.005698
13.8	42°-42.5°	21.29355	21.29177	0.001786	0.008386	0.008387
14	42°-42.5°	21.86321	21.8607	0.002509	0.011475	0.011477
14.2	42°-42.5°	22.44093	22.4376	0.003332	0.014849	0.014851
14.5	42°-42.5°	23.32249	23.31788	0.004612	0.019774	0.019778
15	42°-42.5°	24.83174	24.82491	0.006832	0.027514	0.027522

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As can be seen from Figure 2: under different release velocity, the throwing distance gap is small when the release angle ranges from 42° to 42.5°, about 0.001mto0.007m, 0.001%-0.030% of the maximum throwing distance and 0.003%-0.03% of the minimum throwing distance.

By analyzing the above two groups of deviation data, it can be seen that the deviation of release velocity's impact on the throwing distance is 7-8m, and about 32%-34% of the maximum throwing distance and 47%-52% of the minimum throwing distance. the deviation of release angle' impact on the throwing distance is 0.001-0.007m, and about 0.001mto0.007m, 0.001%-0.030% of the maximum throwing distance and 0.003%-0.03% of the minimum throwing distance.

As a result, the impact of release velocity on throwing distance is much higher than that of release angle on throwing distance. This result indicates that the main focus should be on increasing the release velocity in the training process.

5. CONCLUSIONS AND SUGGESTIONS

The following conclusions can be reached based on the above model analysis: Within the tolerance range of the best shot angle, for the same athletes, sliding speed is the most important external factor that affects the throwing distance and the second important factor is release height. Therefore, more attention should be paid to the strengthening of the sliding movement and the practice of release velocity. Athlete should choose the best release angle adaptable to oneself based on the specific circumstances, rather than excessive pursuit of the best theory release angle.

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