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The impact statistical analysis of the shot throwing speed and angle on results based on numerical simulation

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ABSTRACT

This paper uses Newtonian mechanics etc. physics, mathematics knowledge to establish a mathematical model of the shot put throwing process, discusses three main factors shot speed, shot height and shot angle that impact shot throwing achievements, and then analyzes using numerical method, calculates the influence degree of the various influencing factors on shot throwing distance, and determines the primary and secondary relationship between the influencing factors. The numerical analysis shows that the optimal shot angle of Shot Putters is between 42°-42.5°. The impact deviation of shot velocity on throwing distance is about 7-8m, accounting for 32%-34% of the farthest throwing distance, and accounting for 47%-52% of the nearest throwing distance. While the impact deviation of shot angle on throwing distance is about 0.001-0.007m, accounting for 0.001%-0.030% of the farthest throwing distance, and accounting for 0.003%-0.03% of the nearest throwing distance.

KEYWORDS

Shot put;
Numerical methods;
Optimal shot angle;
Farthest throwing distance.

INTRODUCTION

Shot's throwing motion is that an athlete holds a 7.264kg (16 pounds) weight shot throws out the shot in a throwing circle with a diameter of 2.135m and makes the shot fall into the effective fan-shaped area with an opening angle of 34.92°. The distance between the shot landing point and the throwing circle is used to measure the shot throwing distance, and the size of the shot throwing distance is used to assess the athletes' performance.

This paper uses computer simulation to create a mathematical model, and the predicted throwing distance is expressed as a function of initial velocity and shot angle. Then it uses numerical method to analyze, calculates the influence degree of various factors on shot throwing distance, determines the primary and secondary relationship between the factors, and provides a scientific basis for the establishment of scientific shot training programs.

PROBLEM ANALYSIS AND ASSUMPTION

As how to make the shot put throw the farthest, we just need to obtain the standing time in the air and the speed of the shot in the horizontal direction. The standing time in the air after shot throwing can be obtained by the time that moving with the upward speed to motionless in the vertical direction and falling freely to the ground from the peak point.

Basic assumptions

(1) When shot is moving in the air, the air resistance it receives is small and can be ignored;
(2) Shot's movement in the horizontal direction can be seen as approximate uniform linear motion;
(3) Shot receives only gravity in the vertical direction movement which can be approximately seen as a uniform variable speed linear motion;
(4) When the shot is throwing out, the athlete has arrived to the border of the thrown circle, the throwing distance is equal to the movement distance in the horizontal direction;
(5) Ignore altitude's effect, the gravitational acceleration is 9.8m/s2;
(6) Circular constant pi π is expressed by 3.14;
(7) Shot is a particle;
(8) Shot velocity is regardless of the shot angle.

Symbol description

t: Exercise time$_{(s)}$ in the air after shot throwing;

t_1: The time moving with the upward speed to motionless in the vertical direction after shot throwing;

t_2: The time falling freely to the ground from the peak point in the vertical direction after shot throwing;

v: The initial velocity after shot throwing;

$v$horizontal: The initial component velocity in the horizontal direction after shot throwing;

$v$veritical: The initial component velocity in the vertical direction after shot throwing;

α: The initial shot angle after s: The shot height after shot throwing;

h: The advance distance moving to the first static time;

h_1:: The height of the highest point from the ground in the vertical direction after Shot throwing;

h_2: Gravity acceleration after shot throwing;

g: The measured results of shot throwing;

MODEL BUILDING

Graph schematic

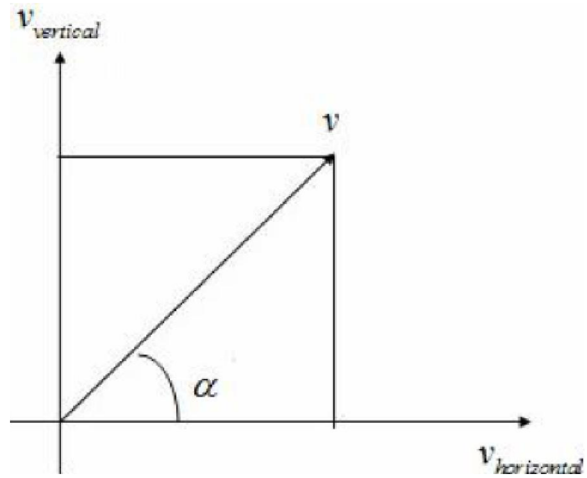

Figure 1 : Velocity relational graph

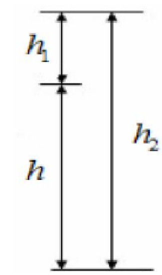

Figure 2 : Height relational graph

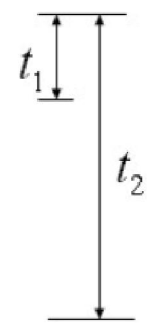

Figure 3 : Flight time relational graph

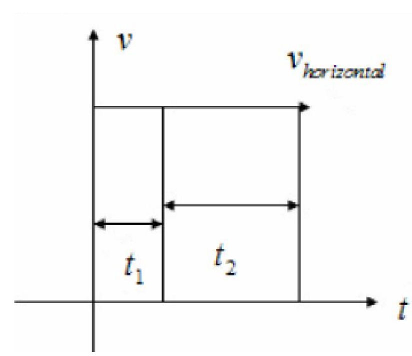

Figure 4 : Velocity time relational graph

Solving the function according to the graph schematic

$v_{horizontal} = v\cos\alpha$; $v_{vertical} = v\sin\alpha$; $h_1 = \frac{v^2_{vertical}}{2g}$; $t_1 = \frac{v_{vertical}}{g}$; $t_2 = \sqrt{\frac{2h_2}{g}}$; $h_2 = h + h_1$; $t = t_1 + t_2$

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$s = v_{horizontal}t$.

Mathematical modeling

Collect above function and simplify it we can draw the following functions:

$$s = \frac{v\cos\alpha}{g}\left(v\sin\alpha + \sqrt{2gh + v^2\sin^2\alpha}\right)$$

Model testing: according to the reference data, calculate the test results and compare them with the experimental results; calculate the error, as shown in TABLE 1 and TABLE 2.

Above TABLE 1 and TABLE 2 shows the relative error is about 1%, so the model is reasonable.

TABLE 1 : Shot put calculated results and measured results of Li mei-su and slupianek

Name	Shot speed(m/s)	Shot height (m)	Shot angle(°)	Actual measurement results(m)	Calculated value(m)	Relative error (%)
Li Mei-su	13.75	1.9	37.6	20.95	20.85634	0.447081
Li Mei-su	13.52	2	38.69	20.3	20.42529	0.617181
SLUPIANEK	13.77	2.06	40	21.41	21.25415	0.727929

TABLE 2 : The calculated results and measured results of Chinese Elite athletes Shot Put

Name	Shot speed(m/s)	Shot height (m)	Shot angle(°)	Actual measurement results(m)	Calculated value (m)	Relative error (%)
Li Mei-su	13.16	40.27	2.02	19.4	19.55627	0.8055
Li Mei-su	13.51	38.69	2	20.3	20.39805	0.483017
Huang Zhi-hong	13.58	37.75	2.02	20.76	20.53161	1.100145
Sui Xin-mei	13.95	39	2.04	21.66	21.67896	0.087557
Li Mei-su	14.08	35.13	1.95	21.76	21.49256	1.229049

SOLVING THE MODEL

The model shows that factors influencing Shot throwing distance include shot height h, shot speed v and shot angle α. In the oblique throwing problem ($s = \frac{v^2\sin 2\alpha}{2g}$), obtain that the optimal launch angle is 45°. In the shot put throwing process, due to the influence of shot speed v and shot height h, the optimal shot angle drifts about 45°. So with different shot velocity v and different shot height h, the optimal shot angles are different. When a fixed shot velocity v and shot height h are given, we can calculate the optimal shot angle under the maximum throwing distance by numerical method.

Observe reference data, the shot speed v = 13.5m/s, shot height h = 2m, the α is divided into 30 intervals with equal length from 35° to 50°, find the approximate range of the optimal shot angle.

According to Figure 5 and TABLE 3 above, the shot velocity v = 13.5m/s, the shot height h = 2m, the longest throwing distance s = 20.4993, the optimal shot angle α = 42°, and the approximate range of shot angle is between 40° to 44°.

Similarly, in the reference data, calculate the shot

TABLE 3 : Numerical simulation

α	v	g	h	s	α	v	g	h	s
35	13.5	9.8	2	19.97182	43	14	9.8	2	20.49353
35.5	13.5	9.8	2	20.04114	43.5	14	9.8	2	20.48297
36	13.5	9.8	2	20.10576	44	14	9.8	2	20.46718
36.5	13.5	9.8	2	20.16564	44.5	14	9.8	2	20.44614
37	13.5	9.8	2	20.22072	45	14	9.8	2	20.41984
37.5	13.5	9.8	2	20.27097	45.5	14	9.8	2	20.38827
38	13.5	9.8	2	20.31633	46	14	9.8	2	20.35142
38.5	13.5	9.8	2	20.35677	46.5	14	9.8	2	20.30928
39	13.5	9.8	2	20.39225	47	14	9.8	2	20.26184
39.5	13.5	9.8	2	20.42273	47.5	14	9.8	2	20.20911
40	13.5	9.8	2	20.44818	48	14	9.8	2	20.15108
40.5	13.5	9.8	2	20.46856	48.5	14	9.8	2	20.08776
41	13.5	9.8	2	20.48385	49	14	9.8	2	20.01913
41.5	13.5	9.8	2	20.49402	49.5	14	9.8	2	19.94522
42	13.5	9.8	2	20.49903	50	14	9.8	2	19.86602
42.5	13.5	9.8	2	20.49888					

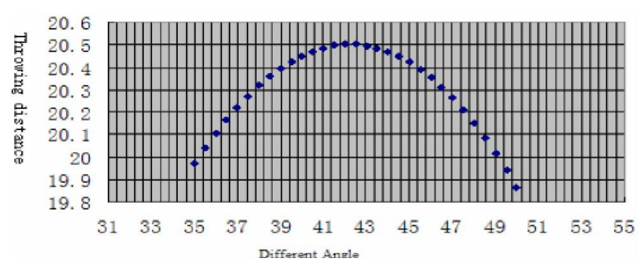

Figure 5 : Best shot angle

angle when the throwing distance is the farthest, and obtain TABLE 4.

TABLE 4 : The shot angle of Su-mei and Slupianek with the farthest Shot throwing distance

Name	Shot speed $v(m/s)$	Shot height $h(m)$	Shot angle $\alpha(^\circ)$	Actual measurement results(m)	Farthest throwing distance(m)	Best shot angle α(°)
Li Mei-su	13.75	1.90	37.60	20.95	21.10672	42.4,42.5
Li Mei-su	13.52	2.00	38.69	20.30	20.55499	42.2
SLUPIANEK	13.77	2.06	40.00	21.41	21.3089	42.3

TABLE 5 : The shot angle of Chinese elite athletes with the farthest Shot throwing distance

Name	Performance s(m)	Shot speed $v(m/s)$	Shot angle $\alpha(^\circ)$	Shot height $h(m)$	Farthest throwing distance(m)	Best shot angle α(°)
Li Mei-su	19.40	13.16	40.27	2.02	19.58812	42.1
Li Mei-su	20.30	13.51	38.69	2.00	20.52728	42.2
Huang Zhi-hong	20.76	13.58	37.75	2.02	20.73984	42.2
Sui Xin-mei	21.66	13.95	39.00	2.04	21.80214	42.3,42.4
Li Mei-su	21.76	14.08	35.13	1.95	22.09334	42.5

TABLE 6 : Throwing distance under different shot angle when shot speed changes from 12m/s to 15m/s

Different shot angles (°)	Change range of shot speed	Farthest throwing distance(m)	Nearest throwing distance(m)	Distance gap(m)	Deviation from the farthest distance (%)	Deviation from the nearest 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

TABLE 7 : Throwing distance under different shot speed when shot angle changes from 42° to 42.5°

Different shot speeds(m/s)	Change range of shot angle	Farthest throwing distance(m)	Nearest throwing distance(m)	Distance gap(m)	Deviation from the farthest distance (%)	Deviation from the nearest 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

The above data shows that: different players have the different optimal shot angles; for the same player with different shot speeds and shot heights, the optimal shot angle is also different, but basically distributed between 42°-42.5°. So by the numerical method analysis, the optimal shot angle of shot putters is between 42° -42.5°.

Calculate the throwing distance with different shot angles when the shot speeds changes from 12m/s to 15m/s using EXCLE as shown in TABLE 6 (assuming the shot height h = 2m):

From the above TABLE: with different shot angles, the throwing distance variation is large when the shot speed changes in 12m/s-15m/s, approximately 7m to 8m, accounting for 32%-34% of the farthest throwing distance, accounting for 47%-52% of nearest throwing distance.

Use EXCLE to calculate the throwing distance at different shot speeds and shot angle changes from 42° to 42.5°as shown in TABLE 7:

From the above TABLE: with different shot speed, the throwing distance variation is small when the shot angle changes in 42°-42.5°, approximately 0.001m to 0.007m, accounting for 0.001%-0.030% of the farthest throwing distance, accounting for0.003%-0.03% of the nearest throwing distance.

CONCLUSIONS

Through this research, we know that the impact deviation of shot velocity on throwing distance is about 7-8m, accounting for 32%-34% of the farthest throwing distance, and accounting for 47% -52% of the nearest throwing distance. While the impact deviation of shot angle on throwing distance is about0.001-0.007m, accounting for 0.001%-0.030% of the farthest throwing distance, and accounting for 0.003%-0.03% of the nearest throwing distance. So we can see the impact of shot speed on the throwing distance is much greater than the impact of shot angle on the throwing distance. This result indicates that when the coach is training athletes, the main effort should be concentrated to increase the initial speed of throwing. The mathematical model of shot put established in this paper can also be applied to the discus, javelin or basketball shooting and other throwing issues.

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