Shot put technique biomechanics parameter sensitivity and optimization research

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ABSTRACT

Throwing problem of shot put is always influenced by many factors, so the force of the shot put, the author of this paper is analyzed, using shoot height, arm speed, Angle and throwing distance between contact, from the geometric Angle to analyze the shot put movement situation, establish a relationship with the shot put throw distance function mathematical model of ejection shot to make the model more reasonable, make further optimization of the model, and expounds the rationality of the assumptions of the model.. By further calculation on throwing model, it fixes release height and then solves shot throwing best release angle is $\theta \pm 2k\pi \in (0, \pi/4]$, $k \in N \in$, from which $\theta = 1/2 \arccos(gh + v^2))$ and furthest throwing distance $s = v\sqrt{v^2 + 2gh}/g$. By researching on air resistance and throwing angle relations as well as shot sensitivity throwing problems' sensitivity analysis, finally it gets the conclusion that ignore air resistance is very necessary.

KEYWORDS

Throwing distance; Biomechanics; Physiology and biochemistry; Parameters optimization; Mathematical model.

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INTRODUCTION

Shotput sport in the history of China has been in existence for hundreds of years, because of the movement to improve people's physical quality, improve their health and was deeply loved by the masses of the people, so early when China's shot put is among the highest in the world. But in recent years, China's shot put movement by the block. In 00 in the Sydney Olympic Games, for example, Chinese women's shot put athletes do not have any MEDALS, and even men's shot put, long stagnation in Asia level only, because our country the status quo, as well as in our country face at home and abroad under the pressure of the urgent request we should start from the technology for research and training, etc. As soon as possible, in addition because sports is increasingly fierce, the athletes the points gap between more and more small, small gap will fall from the rankings, as in the third place of the eighth national games and the difference between the champions of 0.1 m, this phenomenon shows the contemporary competition need us in training should be deeper to mining potential, in order to play the biggest potential athletes, with satisfactory results. But how to improve the technical requirements? To improve technology in the shot put many questions to consider, for example, Angle, shoot height and shot speed on the relationship between, to reach best Angle and shot the furthest distance.

There are many scholars both at home and abroad for the problem studied, and achieved fruitful results, for example: someone once to study some film by finally obtained the best Angle for the approximate scope of;. But James g. Hay (1978) gives the best Angle should be based on actual measurement from 38 ° to 42 ° between, in addition, he also concluded that the speed and the relationship between the best Angle for, namely: with the increase of speed, and the best Angle is slightly increased, although close 45 °, but didn't reach 45 °, 45 ° is so an ideal limit state; Liu Benliang (1984) proposed the shot put is land bevel to describe trajectories. Bevel is refers to the shot put something and fall to the ground together by two lines and the Angle of the ground. According to the author's research, the best Angle of 45 °, thus the because of "bevel p and O not equal", so best to 45 ° Angle should be smaller and more reasonable[1]; MiaoWenKe et al. (1984) once said, "according to throwing Angle problem, to achieve the depending degree and the best Angle for, coaches and shot put athletes need to work together to change and correction of throwing the shot put Angle and throwing speed, so as to get the best grades[2]".

In this paper, on the basis of predecessors' research results about how to choose the biggest shot speed and the best Angle for, so far the largest, by establishing mathematical model, it is concluded that the shot put the best throwing patterns. Ignore and verified in the shot put in air movement under the influence of the air resistance is reasonable.

SHOT THROWING MODEL

Shot during throwing process, with release angles difference, shot movement directions will also different, it mainly divides into three cases, as Figure 1 show:
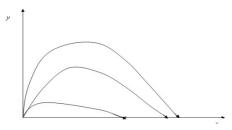

Figure 1 : Shot throwing case

Shot throwing mathematical model

In the model, it ignores throwers mechanical process get involved in throwing circle, at first it carries out research on shot releasing moment throwing angle and initial speed. After shot releasing, due to it moves in a plane, shot in releasing point area vertical direction is movement height $H(t)$, takes time t as x axis to construct rectangular plane coordinate system. After shot leaving out of hand, its movement path can be expressed by rectangular plane coordinate system, when shot moves to t_1 time, then shot arrives at top point, and its speed in vertical direction is 0. As Figure 2 shows[3]:
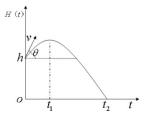

Figure 2 : Shot-put motion path graphic

Analyze above figure, apply momentum theorem, it can get :

$$f \cdot t^3 = mv \Rightarrow v = \frac{f \cdot t^3}{m} \tag{1}$$

While by:

$$v \sin \theta = g t_1 \tag{2}$$

That

$$t_1 = \frac{v \sin \theta}{g} \tag{3}$$

By simplifying calculation, it can get top point:

$$H(t_1) = h + \frac{1}{2} g t_1^2 = h + \frac{v^2 \sin^2 \theta}{2g} \tag{4}$$

By adding coefficient, it can get parabola equation is:

$$H(t) = a(t - \frac{v \sin \theta}{g})^2 + h + \frac{v^2 \sin^2 \theta}{2g} \tag{5}$$

When time arrives at $t = 0$:

$$H(0) = a \frac{v^2 \sin^2 \theta}{g^2} + h + \frac{v^2 \sin^2 \theta}{2g} = h \tag{6}$$

So it can get:

$$a = -\frac{g}{2} \tag{7}$$

Input formula (7) into formula (6), it can get:

$$H(t) = -\frac{g}{2}(t - \frac{v\sin\theta}{g})^2 + h + \frac{v^2\sin^2\theta}{2g} \tag{8}$$

Assume $H(t_2) = 0$, it gets:

$$t_2 = \sqrt{\frac{2h}{g} + \frac{v^2\sin^2\theta}{g^2}} + \frac{v\sin\theta}{g} \tag{9}$$

Due to:

$$S = v\cos\theta \cdot t_2 \tag{10}$$

In case release height is known, thrower and shot landing point distance:

$$S = \sqrt{\frac{2hv^2\cos^2\theta}{g} + (\frac{v^{2\sin2\theta}}{2g})^2} + \frac{v^2\sin2\theta}{2g} \tag{11}$$

According to above formula, we can get distance, speed, angle, height function relationships.

Define best throwing mode

       After given release height, to different release speeds, we should define best release angle. Obviously, it is extreme value problem, according to calculus knowledge; it should firstly solve stagnation point. By formula (11), it can get $S(v, h, \theta)$ is speed and height's one kind of monotonic function, and is also θ maximum point, therefore we can get by differential, that:

$$\partial S / \partial\theta = 0 \tag{12}$$

So:

$$\frac{dS}{d\theta} = v^2\cos2\theta g + \frac{v^4\sin2\theta\cos2\theta - 4hv^2\cos\theta\sin\theta g}{\sqrt{\frac{v^4\sin^2 2\theta}{g^2} + 8\frac{hv^2\cos^2\theta}{g}}} = 0 \tag{13}$$

After simplifying, it is:

$$v^2\cos2\theta\sqrt{v^4\sin^2 2\theta + 8hgv^2\cos^2\theta} + v^4\sin2\theta\cos2\theta - 4hgv^2\cos\theta\sin\theta = 0 \tag{14}$$

By converting, it gets:

$$\cos 2\theta = \frac{gh}{gh+v^2} = \frac{g}{g+\dfrac{v^2}{h}}$$

(15)

By formula (15), it is known that to fixed release height h, if speed increases, then corresponding best release angle θ will also increase, in the following we make further analysis of formula (15), according to situation $\theta > 0, h > 0$ so $\cos 2\theta > 0$, and then $0 < \theta \le \dfrac{\pi}{4}$, therefore we get best release angle:

$$\theta = \frac{1}{2}\arccos(\frac{gh}{gh+v^2})$$

(16)

$$S = \frac{v}{g}\sqrt{v^2 + 2gh}$$

Similarly it can solve throwing furthest distance is:

(17)

Due to θ period is 2π, when $\theta \pm 2k\pi \in \left(0, \dfrac{\pi}{4}\right), k \in N$, $\theta \pm 2k\pi$ is best throwing shot release angle, especially when $h = 0$, at this time $\theta = 45^0$.

AIR RESISTANCE AND THROWING ANGLE BEST ANGLE RELATIONS DISCUSSION

Regarding shot throwing mathematical model establishment and solution, it discusses in case that assume ignoring air resistance, so when it has resistance, formula (11) will not at work anymore, so we reconstruct shot movement trajectory equations, their corresponding construction process is as following:

$$mx = -kx\sqrt{x^2 + y^2}$$

(18)

$$my = -mg - ky\sqrt{x^2 + y^2}$$

(19)

When $t = 0$:

$$y = v_0 \sin \theta$$

(20)

When $t = 0$:

$$x = 0$$

(21)

When $t = 0$:

$$y = h$$

(22)

In above formula, g is gravity accelerated speed.

Air resistant constant is k, then according to fluid mechanical relative knowledge, it can get :

$$k = \frac{1}{2}cqs \tag{23}$$

To formula (23), air resistance coefficient is c, air flow density is q, shot forward movement moment vertical movement direction projection area is s, from which c is defined according to Reynolds number R, that is :

$$R = \frac{gvd}{\mu} \tag{24}$$

Among them, viscosity coefficient is μ, speed is v, shot diameter is d.

By consulting relative documents, we can get $\mu = 0.00001819$, $s = 0.006^2 \mathrm{pi}\, m^2$, $g = 1.293(kg/m^3)$, and let shot throwing release speed value as $v = 10 - 14\, m/s$, and then we can get $R = 8.5 \times 10^4 - 1.6 \times 10^8$, but according to formula (23), we can get that Reynolds number actually extracts value between $2 \times 10^4 - 2 \times 10^8$, c always is a constant that is 0.47, and so according to previous stated conditions, it can solve $k = 3.4 \times 10^{-3}$, by applying formula (18)-(19) we can solve different values corresponding maximum value that is x, in the following, combine golden section ratio with $Runge - kulta$ method, it can get its solution by calculating. The solution is under different shot release initial speeds, different air resistances corresponding different heights, they and achieved best distance and best angle relations, except for that, we can also make comparison with case ignoring air resistance. For different heights in or without air resistance cases, we make numerical analysis of corresponding release speed, release angle and shot flight distance relations, as TABLE 1 and TABLE 3 show.

TABLE 1: Height 2.2m air resistance comparison table

Speed	14.5 m/s	14 m/s	13.5 m/s	13 m/s	12.5 m/s	12 m/s	11.5 m/s	11 m/s	10.5 m/s	10 m/s
Ignoring air resistance	$42^0 19'$ 23.55m	$42^0 09'$ 22.09m	$41^0 57'$ 20.68m	$41^0 45'$ 19.32m	$41^0 30'$ 18.01m	$41^0 15'$ 16.75m	$40^0 58'$ 15.54m	$40^0 39'$ 14.38m	$40^0 17'$ 13.27m	$39^0 53'$ 12.21m
Considering air resistance	$42^0 14'$ 23.34m	$42^0 05'$ 23.34m	$41^0 52'$ 23.34m	$41^0 41'$ 23.34m	$41^0 27'$ 23.34m	$41^0 12'$ 23.34m	$40^0 53'$ 23.34m	$40^0 32'$ 23.34m	$40^0 15'$ 23.34m	$39^0 48'$ 23.34m

TABLE 2 : Height 2.0m air resistance comparison table

Speed	14.5 m/s	14 m/s	13.5 m/s	13 m/s	12.5 m/s	12 m/s	11.5 m/s	11 m/s	10.5 m/s	10 m/s
Ignoring air resistance	$42^0 33'$ 23.36 m	$42^0 23'$ 21.10 m	$42^0 12'$ 20.36 m	$42^0 33'$ 17.83 m	$42^0 01'$ 17.83 m	$41^0 48'$ 16.57 m	$41^0 33'$ 15.37 m	$41^0 17'$ 14.20 m	$40^0 59'$ 13.10 m	$40^0 17'$ 12.04 m
Considering air resistance	$42^0 32'$ 23.19 m	$42^0 21'$ 21.75 m	$42^0 10'$ 20.36 m	$42^0 33'$ 19.02 m	$42^0 00'$ 17.73 m	$41^0 46'$ 216.49 m	$41^0 30'$ 15.29 m	$41^0 15'$ 14.14 m	$40^0 33'$ 13.05 m	$40^0 14'$ 12.10 m

TABLE 3 : Height 1.8m air resistance comparison table

Speed	14.5 m/s	14 m/s	13.5 m/s	13 m/s	12.5 m/s	12 m/s	11.5 m/s	11 m/s	10.5 m/s	10 m/s

Ignoring air resistance	$42^0 46'$ 23.18 m	$42^0 37'$ 21.73 m	$42^0 28'$ 20.32 m	$42^0 17'$ 18.96 m	$42^0 05'$ 17.65 m	$41^0 52'$ 16.39 m	$41^0 37'$ 15.19 m	$41^0 20'$ 14.03 m	$41^0 02'$ 12.93 m	$40^0 41'$ 11.87 m
Considering air resistance	$42^0 43'$ 23.00 m	$42^0 33'$ 21.57 m	$42^0 22'$ 20.18 m	$42^0 14'$ 18.84 m	$41^0 50'$ 17.55 m	$41^0 32'$ 16.31 m	$41^0 14'$ 15.12 m	$40^0 56'$ 13.97 m	$40^0 40'$ 12.87 m	$40^0 36'$ 11.83 m

By above TABLE 1, TABLE 2, TABLE 3, we can see, ignoring air resistance compares with considering air resistance, the two corresponding best angles are very approximate, but when considering air resistance, corresponding horizontal distance will diminish, and it will increase with release speed increasing, but due to athlete release speed is not big in throwing shot process, therefore for release angle problem, it can ignore air resistance influence.

ABOUT SHOT THROWING PARAMETERS PROBLEMS SENSITIVITY ANALYSIS

By formula (11), we get relations about release speed and release angle as well as release height the three, but athlete more concerned problem is making his shot throwing further so that let his performance surpass others. But we know that for athlete shot release height, it will have no big change, so we make research from shot release speed and release angle so as to pursue the two to shot throwing furthest maximum variable that is comparing the two to shot throwing distance sensitivity research.

Regarding shot throwing moment release angle and initial speed research, it has many methods, formers had ever used fast flash projections several methods, but the method exist some drawbacks, as it wastes time and strength, so it should apply a kind of simpler method to measure shot before landing flight time t, as well as shot threw distance S and corresponding release height H, let formula (6)height $H(t)$ be equal to zero, that : $H(t) = 0$, so it gets :

$$\tan \theta = \frac{\frac{1}{2} g t^2 - h_0}{L} \tag{25}$$

Simplified by formula (2)as :

$$v = \frac{L}{\cos \theta * t} \tag{26}$$

So only measure shot above three corresponding values, and then according to formula (22), (23) connection equations, it can decide initial speed and release angel, and it also unique determination. So we make practical measurement on different levels shot putters, and get following results as TABLE 4, TABLE 5, and TABLE 6:

TABLE 4 : No.1 testee

Throwing times	Best horizontal distance	Best release angle	Release angle	Release initial speed	Horizontal distance	Shot flight time	Release height
1	13.055m	$40^0 45'$	$24^0 51'$	$10.35 m/s$	$11.35 m$	$1''2$	$1.95 m$
2	13.055m	$40^0 45'$	$23^0 46'$	$10.65 m/s$	$11.70 m$	$1''2$	$1.95 m$
3	13.055m	$40^0 45'$	$24^0 08'$	$10.50 m/s$	$11.50 m$	$1''2$	$1.95 m$

TABLE 5 : No.2 testee

Throwing times	Best horizontal distance	Best release angle	Release angle	Release initial speed	Horizontal distance	Shot flight time	Release height
1	9.07m	$39^0 12^/$	$31^0 48^/$	$8.14\,m/s$	8.30m	$1^{//}2$	$1.90m$
2	9.44m	$39^0 42^/$	$24^0 49^/$	$8.71\,m/s$	8.70m	$1^{//}1$	$1.85m$
3	9.07m	$39^0 12^/$	$26^0 30^/$	$8.30\,m/s$	8.20m	$1^{//}1$	$1.87m$
4	9.94m	$39^0 42^/$	$24^0 36^/$	$8.79\,m/s$	8.80m	$1^{//}1$	$1.86m$

TABLE 6 : No.3 Testee

Throwing times	Best horizontal distance	Best release angle	Release angle	Release initial speed	Horizontal distance	Shot flight time	Release height
1	9.81m	40^0	$45^0 41^/$	$8.68\,m/s$	9.10m	$1^{//}5$	$1.65m$
2	9.73m	40^0	$36^0 53^/$	$8.56\,m/s$	8.91m	$1^{//}3$	$1.60m$

In above three testees: the first testee release angel is too small, throwing at angle $40^0 45^/$, and his available achieved or surpassed best result is $13.4m$;the second testee performance from release area to ball drop point is $8.80m$, but his performance is $11.7m$;the third testee performance from release area to ball drop point is $11.7m$, but his performance is $12.1m$;

CONCLUSION

The model obtains release angle α 、 release speed v factor to throwing distance S influences sizes, therefore it has certain guiding values in future athletes competition and training as well as coaches guiding aspects. From above model values, by comparing whether ignoring air resistance research, finally it gets that ignoring shot throwing moment air movement suffered air resistance influence is reasonable. By shot throwing problems' sensitivity analysis, we get athlete best throwing angle and best throwing distance, so it can conclude the model is reasonable, therefore athlete should improve paper mentioned best angle exercising in future training so that can throw best result.

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