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Shot movement process simulation and performance prediction model research based on biomechanical equation

Wei Xiong*, Cheng Yang

Institute of Physical Education, Southwest Petroleum University, Chengdu 610500, Sichuan, (CHINA)

ABSTRACT

Make mechanical analysis of shot movement trajectory, do research on shot promotive release speed and performance, and establishment shot throwing best angle mathematical optimization model, which makes reasonable suggestions on the event training, and provides theoretical basis for coaches and athletes. In shot competitions, throwing distance is final research objective; the paper firstly utilizes kinematics researching on shot detailed movement process, and then analyzes previous Olympic Games shot event data getting Olympic Games shot performance simulation figure, on this basis it establishes performance prediction model. Finally it makes reasonable suggestions on shot putters.

KEYWORDS

Kinematics; Prediction model; Shot performance; Biomechanics.

INTRODUCTION

Shot event has a long history, is a kind of old sports event, and also is modern Olympic Games important field event. The origin of shot event can derive from ancient society. People in ancient period faced hostile living conditions and low productivity, in order to live and multiply, they should possess certain sport abilities. Not only needed to run quickly, crossing each kind of barriers to trace prey, but also should use stone and other simple tools to hunt for food. Till slavery period, human race had wars, in order to improve military fighting capacity; it had throwing Pie weights training and competition in military training. In 1896, Greece Athens held first modern Olympic Games; shot put was listed into men's formal competition event. Shot technique experienced nearly more than 600 years' development process from generation until now. Initial technique is in-situ put and semi side leapfrog shot put. And sports techniques rapidly development started from modern times first modern Olympic Games, it totally went through three phases: semiback-facing sliding shot putting phase; back sliding shot putting phase; back spinning shot putting technique challenge phase. Modern shot put integrity techniques include gripping, holding, sliding or spinning, final exertion and maintaining body balance and others five technical links. Techniques are complicated, difficulty is bigger, it requires athletes have tall figure, super strong explosive power and whole body coordinate exercise capacity.

At present, combine with mechanics and kinematics researching shot event is one of the hotspots. Many scholars have made deepen research, such as Li Jing etc. made "Chinese serving excellent men shot putters' sliding technique kinematical research". They made research on Chinese serving excellent eight shot putters' sliding techniques by three dimensional kinematical analysis method and found our country players universally exist long sliding time, right leg pedaling and extending not active, grounding angle too large, right leg contract and pull not active in sliding process, surpassing apparatus effects not good and other disadvantages, which should be improved in future training. Yang Wen-Xue etc. made "World excellent men shot putters throwing technique biomechanical analysis". They made comparison on athletes' techniques by athletes' technical analyzing provided world excellent men shot putters' biomechanical parameters, analyzed gliding and spinning shot putting techniques and different spinning technical types' existed differences. Put emphasis research on shot itself and athletes' body accelerated problems, and so further got athletes and shot such system acceleration to release phase shot final acceleration motions sequence process change features, which provided theoretical basis for high-level shot putters' technical training.

The paper on that basis, makes use of kinematics and mechanics to research shot detailed movement process, and then analyzes previous Olympic Games shot event data, and gets Olympic Games shot performance simulation chart, based on that, it establishes performance prediction model.

MOVEMENT PROCESS RESEARCH

By observing shot movement process, the paper divides the process into two phases: push process and shot flight process in the air. Due to shot its own mass is big enough, the paper ignores air resistance to it, and then respectively researches on the two process.

Push process

In the process shot state is during acceleration, assume that accelerated speed is fixed as a, in pushing process, it pushes an arm length of l, ball out of hand moment speed is v, set shot acceleration time is t_1, according to kinematics, it can get:

$$\mathbf{l = \frac{1}{2} a t_1^{\,2}} \tag{1}$$

$$\mathbf{v = a t_1} \tag{2}$$

Simultaneous formula (1), (2), it can get:

$$v = \sqrt{2al}$$

Air flight process

Shot flight process state in the air is as Figure 1 show, the paper divides the process into two parts that are respectively shot moving from release point to highest point and moving from highest point to landing point.

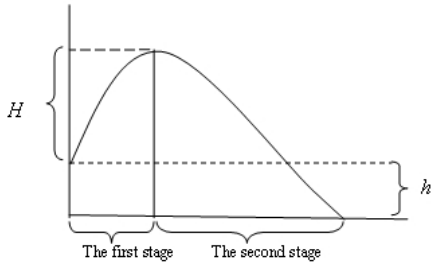

Figure 1 : Air flight process

Assume that shot drop point and release point distance is s, when shot rising height is H, spend time is t_2, time for shot falling from highest point to ground is t_3, shot air movement total time is T. By Newton kinematical formula, it can get:

Phase that shot moves from release point to highest point:decompose speed v into horizontal direction and vertical direction speed component that are respectively v_x and v_y, and $v_x = v\cos\theta$, $v_y = v\sin\theta$, as Figure 2.

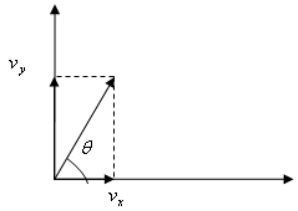

Figure 2 : Speed decomposition

Drop point and release point distance $s = v_x \cdot T$, shot total time in the air $T = t_2 + t_3$, shot rises to highest time $t_2 = \frac{v_y}{g}$.

From shot highest point to landing point phase: $t_3 = \sqrt{\frac{v_y^{\,2}}{g^2} + \frac{2h}{g}}$, for t_3, because shot putters' heights are generally within $1.8m$, so $\frac{2h}{g} \le 0.36$, they have smaller increment to t_3, so $t_3 = \sqrt{\frac{v_y^{\,2}}{g^2} + \frac{2h}{g}} \approx \frac{v_y}{g}$. Therefore $t_2 = t_3 = \frac{v_y}{g}$, it solves $s = \frac{v^2}{g} \cdot \sin 2\theta$. So when shot running speed to a certain degree, when $\theta = 45^\circ$, s is maximum.

For result, it makes suggestions: in shot event, to get relative excellent performance, according to above conclusion, we can see distance $s = \frac{v^2}{g} \cdot \sin 2\theta$, therefore to get excellent performance in shot event,

it should change v and θ. It makes following suggestions: control release speed v to be enough big, it needs to promote accelerated speed sizes in accelerated speed process; For hands throwing moment ball throwing direction and horizontal direction included angle θ keeps around 45 degree.

PERFORMANCE PREDICTION MODEL

Model establishment

In 1838, Belgium biologist Pierre Francois Verhulst presented retardant growth model. Lots of different surfaces things after making reasonable simplifying hypothesis according to their internal functions construct retardant growth models. Therefore it is widely applied into mathematics, biology, economics and management as well as others multiple fields, it includes continuous and scatter two forms.

Considering competition environment, human body physical ability, competitiveness and other factors retardant effects on sports performance, the paper makes use of retardant growth model to make analysis and prediction on shot performance. Retardant effects reflect in shot event growth rate r influences, let r diminish with performance x increasing. If represent r as x function $r(x)$.

$$\frac{\mathbf{dx}}{\mathbf{dt}} = \mathbf{r(x)x(t), x(0) = x_0} \tag{3}$$

Assumption to $r(x)$ is, set $r(x)$ as x linear function, that is :

$$\mathbf{r(x) = r - sx \quad (r > 0, s > 0)} \tag{4}$$

Given due to people body physical ability extreme and athletes' physical quality, growth rate x_m, when $x = x_m$, performance will not grow any more that growth rate $r(x_m) = 0$, input formula (4), it gets $s = \frac{r}{x_m}$, so formula (4)is:

$$\mathbf{r(x) = r\left(1 - \frac{x}{x_m}\right)} \tag{5}$$

Input (5) into (3) equation, it gets:

$$\begin{cases} \dfrac{\mathbf{dx}}{\mathbf{dt}} = \mathbf{rx\left(1 - \dfrac{x}{x_m}\right)} \\ \mathbf{x(0) = x_0} \end{cases} \tag{6}$$

Solve equation (6), it can get:

$$\mathbf{x(t) = \frac{x_m}{1 + \left(\frac{x_m}{x_0} - 1\right)e^{-rt}}} \tag{7}$$

Expression (7) is retardant growth model standard equation.

Model solution

Retardant growth model is : $x(t) = \dfrac{x_m}{1 + \left(\dfrac{x_m}{x_0} - 1\right)e^{-rt}}$

Take reciprocal on equality two sides, it gets : $\frac{1}{x(t)} = \frac{1+\left(\frac{x_m}{x_0}\right)e^{-rt}}{x_m}$, That : $\frac{1}{x(t)} = \frac{1}{x_m} + \left(\frac{1}{x_0} - \frac{1}{x_m}\right)e^{-rt}$

In shot event sports state change process, it makes statistics shot performance data from first Olympic Games in 1896 to London Olympic Games in 2012; list is as following TABLE 1.

TABLE 1 : Each session summer Olympic Games shot performance statistics table

Vintage/Year	Gold medal performance/m	Silver medal performance/m	Bronze medal performance/m
1896	11.22	11.20	10.36
1900	14.10	12.85	12.37
1904	14.81	14.40	13.37
1908	14.21	13.62	13.18
1912	15.34	15.25	13.93
1920	14.81	14.15	14.15
1924	14.99	14.89	14.64
1928	15.87	15.75	15.72
1932	16.00	15.67	15.61
1936	16.20	16.12	15.66
1948	17.12	16.68	16.42
1952	17.41	17.39	17.06
1956	18.57	18.18	17.65
1960	19.68	19.11	19.01
1964	20.33	20.20	19.39
1968	20.54	20.12	20.09
1972	21.18	21.17	21.14
1976	21.05	21.03	21.00
1980	21.35	21.08	21.06
1984	21.26	21.09	20.97
1988	22.47	22.39	21.99
1992	21.70	20.96	20.94
1996	21.62	20.79	20.75
2000	21.29	21.21	21.20
2004	21.16	21.16	21.07
2008	21.51	21.09	21.04
2012	21.89	21.59	21.23

Use Matlab drawing pictures, mark out each session summer Olympic Games shot champions performance roughly trends, figure is as following Figure 3.

By above Figure 3, it finds Olympic Games shot performance will appear a rapid growing logarithmic phase, when arriving at maximum growth rate, after that due to human body own physical ability restriction conditions, let growth rate gradually reduce, shot throwing distance will slowly growing and finally arrives at maximum value's stable period, growth curve shows *s* type. Olympic Games shot event performance growth situation can analogical to retardant growth model, hereby it adopts retardant model predicting Olympic Games shot event performances.

To predict previous Olympic summer Games shot performance, it consults five years' Olympic summer Games champions' performance from 1952 to 1968, data is as TABLE 2.

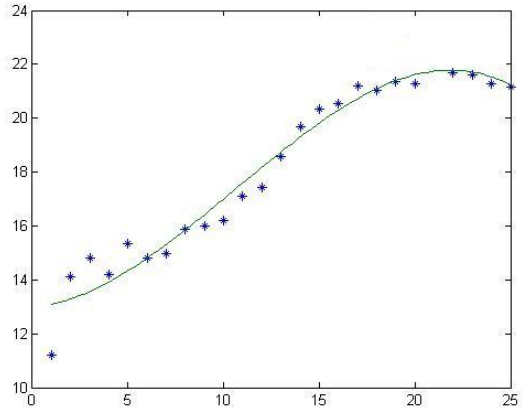

Figure 3 : Shot performance trend figure

TABLE 2 : Olympic Summer Games champions performance from 1952 to 1968

Years	1952	1956	1960	1964	1968
Gold medal performance	17.41	18.57	19.68	20.33	20.54

Regard year 1952 as starting time, that $t = 0$, year 1968 is ending time, that $t = 4$ make non-linear fitting with above table data, apply Matlab program, it gets relative parameters, that $r = 0.0888$ and $x_m = 22.5954$.

Input (7), it gets :

$$x(t) = \frac{x_m}{1 + \left(\frac{x_m}{x_0} - 1\right)e^{-rt}} = \frac{22.5954}{1 + 0.2978e^{-0.0888t}} \quad \textbf{(8)}$$

By above formula, it solves year 1972 ~1988 predicted values as TABLE 3.

TABLE 3 : Year 1972 ~1988 Olympic Games performance predicted value

Year	1972	1976	1980	1984	1988
True value	21.18	21.05	21.35	21.26	22.47
Predicted value	21.138	20.972	21.222	21.119	22.304
Error	0.042	0.078	0.128	0.141	0.166

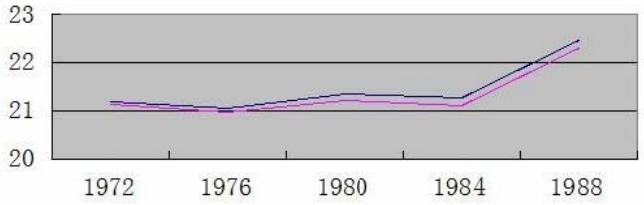

Figure 4 : Year 1988 ~2004 Olympic Games shot predicted value and true value comparison

By Figure 4, it can see assume that Olympic Games performance growth in retardant model, predicted value gets relative closer to true value, error is smaller.

CONCLUSIONS

The paper carries out analysis of shot movement process and shot movement data by kinematics, mechanics and retardant growth model. At first, according to shot movement process state differences, divide it into push process and air flight process two phases. Control release speed to be big enough, it needs to promote accelerate speed sizes in acceleration process. By statistics Olympic Games shot performance data from year 1896 to 2012, use Matlab drawing out performance roughly trend, it concludes: Olympic Games shot event performance growth situation can analogous to retardant growth model, hereby it adopts retardant model predicting Olympic Games shot event performance. By establishing above model, it presents relative reasonable suggestions with regard to how to let shot putters get good results in competition: at ordinary training, athletes should strengthen physical quality and psychological quality training; control optimal release angle, athlete should master correct exertion order; make more arm strength training

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