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Prediction and dynamic model of high jump performance based on block growth model

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ABSTRACT

In order to improve the achievement of high jumpers, this study first approximately launches a jump height model based on the three stage model as the run-up, take-off and crossing bar. In the take-off stage, to accelerate the run-up velocity and strength athlete' the power to jump are two main directions to enhance the performance. And to increase the take-off velocity in the crossing bar stage plays an important role in enhancing the results. Then based on the men's and women's high jump champion achievement data in the Olympic Games, this study establishes the block growth prediction model of men's and women's high jump performance and predicts that the scores of men's and women's high jump champion of the 30th Olympic Games are accordingly 2.3845m and 2.0707m. The predicted results are highly in coincide with the existing 30th Olympic Games results of men's and women's high jump, which are 2.38m and 2.05m respectively, indicating that this model is suitable for the prediction of high jump performance and can provide a reference for the training work of high jump coaches and athletes..

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KEYWORDS

High jump;
Block growth model;
Dynamic model;
Prediction.

INTRODUCTION

After 100 years of development, the high jump has reached a very high level. Whereas, studies on the dynamics and mechanical characteristics of the high jump, as well as on predicting athletes' performance still have great significance to promote the improvement of the jump high level. There are a large number of scholars in the past studying on the dynamics of the high jump, but mostly they focus on the analysis of the kinematic characteristics of all aspects of high jump. And studies on the various stages of movement of the athlete as a whole are very rare. In fact, different technical stages of the high jump are closely linked. Therefore, to conduct mechanical analysis of the high jumpers' height in general is very necessary. High jump results are in a rising process and scientific predictions of future achievements can specify the day-to-day training of athletes. In the past, prediction on the high jump performance is usually about the game time and scores based on the regression model and gray prediction model. However, with the gradually slow growth rate of the high jump achievements, the predicted results with the above methods tend to have larger differences with the actual situation.

In this study, first create a dynamic model of the high jump height and analyze the various factors' effect on the jump height. Then establish block growth prediction model according to the men's and women's championship results in the Olympic Games. This study aims at providing certain referencing basis for the training work of high jump coaches and athletes.

RESEARCH ON THE DYNAMIC MODEL OF HIGH JUMP

Fundamental analysis of the high jump process and height

The Fosbury Flop can be divided into three steps:

(1) Run-up: run-up line is generally "J". The preparatory segment of the run-up is a straight line or a small curvature line, and then gradually transfers to arc, with the arc curvature from big to small, to gradually increase the body' internal frequency. (2) Take-off: the horizontal velocity obtained from the run-up can be rapidly transferred to vertical upward movement velocity, so that the body is fully upward Jumping and ready to cross the bar. Take-off action can be divided into the jumping leg's landing, buffering and stretching, three stages in general and the coordination between the swing legs and arms. (3) Crossing bar and landing: the crossing bar is to make full use of the take-off flight time to change body posture, and take advantage of the range of motion of the body and rotate over the bar.

High jump height H is composed of three parts:

(1) H_1: The height of body center of gravity before vacation. It depends on the athlete's height and leg length, and apparently the athletes with tall height and long legs have a clearly advantage on the height of gravity center. It can be decomposed into h_1, h_2. h_1 means the height from the ground to the body center of gravity when the knees buffer to the greatest extent since the take-off foot's landing. h_2 means the result that the height of body center of gravity at the take-off moment minus h_1. (2) H_2: The vertical distance from the highest point in the vacation to the height of body center of gravity height before the vacation. (3) H_3: The vertical distance from the body center of gravity to cross bar in the highest point of vacation. It depends on the air posture when the athlete reaches the highest point and the body movements when crossing the rod.

$H = H_1 + H_2 + H_3$

Construction of the mathematical model

Run-up stage: Assumptions: The preparatory segment of run-up is uniformly accelerated linear motion. The curve segment is variably accelerated circular motion. Do not consider the resistance from winds to the body. Man is taken as a particle.

Symbol Description: a - Acceleration of the uniformly accelerated linear motion; F - Friction suffered by the body; R - Radius of the curve.

The eventually established mathematical model is: Line segment: $v = a \times t$; Curve segment: $v^{02} = F \times R / m$

Take-off stage: Model assumptions, Buffering stage: from the landing to the hopping foot to knees' buffering to the maximum extent. As this takes place in an instant, the dropping of the center of gravity can be regarded as a uniform decelerated motion. And the body receives only the supportive force in the vertical direction from the ground, gravity and the resistance in the horizontal direction. Changes of horizontal velocity and vertical velocity are independent of each other.

Kicking stage: the center of gravity is on a rapid shift and the thighs kick straight. Besides, the center of gravity of the person is in the same line with the reaction force. The human body is in upward swing in the vertical direction. This happens in a short time and the force in this process is constant force, so this stage can be approximately regarded as a uniformly accelerated motion.

The eventually established mathematical model:

Buffering:

Horizontal direction: $-f_1 \times t_0 = mv_{1x} - mv_1$ [Theorem of impulse]

Vertical direction: $v_{1y} = \left[\left(mg - f_2 \right) / m \right] / t_0$; $\Delta H = \frac{1}{2} g t^2$.

Kicking: $F \times \Delta t = mv_{2y} - \left(-mv_{1y} \right)$ [Theorem of impulse]

Crossing bar stage:

Assumptions:

The athlete is regarded as a particle, i.e. the center of gravity is the particle. When people do projectile motion in the air, the body only receives the force of gravity and the air resistance is ignored.

Symbol Description: a - Flight angle; d - The vertical distance of jumping-off point to the rod; h - The take-off vertical height; v_2 - The take-off velocity.

Modeling:

Horizontal direction: $v_2 * \cos a * t = d$ [Projectile Motion]

Vertical direction: $v_2 * \sin a * t - \frac{1}{2} * g * t^2 = h$

By the models of the three stages: the run-up, take-off and the cross bar, it can be approximately established that:

$$H = H_1 + H_2 - H_3 = H_1 + \left[v_2 * \sin a * t - \frac{1}{2} g t^2 \right] + H_3$$

Analysis on the mathematical model of the take-off stage and the crossing bar stage:

(1) Formula for the take-off stage:

Buffering:

Horizontal direction: $-f_1 * t_0 = mv_{1x} - mv_1$ [Theorem of impulse],

Vertical direction: $v_{1y} = \left[(mg - f_2)/m \right] / t_0$;

$$\Delta H = \frac{1}{2} \left[(mg - f_2)/m \right] * t_0^2$$

(The dropping height of the center of gravity is in fact the rising height of the center of gravity)

Kicking: $F * \Delta t = mv_{2y} - (-mv_{1y})$ [Theorem of impulse]

Therefore, factors affecting the take-off velocity v_2 and flight angle a are the vertical rising height of the center of gravity ΔH and take-off time Δt in the take-off stage. To increase the take-off velocity means to increaseand.

As for, the increasing ofwill increase. So fast run-up can increaseand shorten the impact time. Judging from, it can be drawn that increases.

As for v_{2y}, the increasing of F and decreasing of v_{1y} will both increase. However, to reducewill be reduce, so to increaseis a major factor.

In summary, to accelerate the run-up velocity and the athlete's power to jump are the main directions to increase H_2. In the take-off stage, with the fast upward swing of swing legs and arms and stretching the joints of hopping foot, a strong kicking action will be formed. This will increase the power of people to jump and can increase the take-off power.

(2) Formula for the crossing bar stage:

$v_2 * \cos a * t = d$; $v_2 * \sin a * t - \frac{1}{2} * g * t^2 = h$

As can be seen from the formula: If the center of gravity falls in front of the crossbar, that may result in that the body will touch the rod in the down process, that is: $v_2 * \sin a < gt$

Suppose: $v_2 * \sin a * t - \frac{1}{2} g * t^2 = h < H_0$ (The height of the bar)

If the center of gravity falls on the upper back of the crossbar vertical plane, the body will probably touch the bar in the up process, that is: $v_2 * \sin a > gt$

Similarly suppose: $v_2 * \sin a * t - \frac{1}{2} * g * t^2 = h < H_0$ (The height of the bar)

Reasonable take-off velocity and take-off distance should satisfy the following formula:

$v_2 * \cos a * t = d$; $\left[v_2^2 * \sin^2 a \right] / (2g) = H_2$

In the formula: $H_2 = \left[v_2^2 * \sin^2 a \right] / 2g$

To make H_2 as larger as possible should increase at the same time: (1) increase the take-off velocity v_2; (2) increase the flight angle a. $v_2^2 = v_{1x}^2 + v_{2y}^2$

The flight angle of high jump is formed by the horizontal direction and the direction of the initial velocity when the body center of gravity vacates and the body is off the ground. It is related with the ratio of the vertical angle at the take-off instant to the horizontal velocity (when the vertical angle is larger than the horizontal velocity, $a > 45^\circ$, when the vertical angle is smaller than the horizontal velocity, $a < 45^\circ$). Through the sine is the largest when $a = 90^\circ$, it is not possible to use the jumping angle of 90°. The main reason is that the main purpose of high jump is to cross the bar and at the same time to take advantage of the run-up level velocity to accelerate the take-off action. And the sensitivity of a is not high, so that the change scope of H_2 is limited. Therefore, to increase the take-off velocity v_2 has an impor-

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tant role in improving the value of H_2.

RESEARCH ON THE BLOCK GROWTH PREDICTION MODEL OF HIGH JUMP PERFORMANCE

The principle of block growth model

Assume that the growth rate of high jumper's result r is the linear decreasing function of the original result of high jump x . In other words, the growth rate of high jump result will decline with the increasing of the high jump result: $r(x)=r_0-sx$

Therefore athlete' high jump result will finally reach saturation and tends to a constant x_m . When $x = x_m$, the growth rate is 0. $r_0-sx_m=0$

From the above relation, it can be derived that: $r(x)=r_0\left(1-\frac{x}{x_m}\right)$

Substitute the above equation into the equations of exponential growth model. And based on the initial conditions $x(t_0)=x_0$, it can be obtained that: $\begin{cases}\frac{dx}{dt}=r_0\left(1-\frac{x}{x_m}\right)x\\ x(t0)=x0\end{cases}$

After calculation: $x(t)=\frac{x_m}{1+\left(\frac{x_m}{t0}-1\right)e^{-r(t-x0)}}$

Symbol description

r - Growth rate of high jumper's result; x - Original result of high jump; x_m - The limit of high jump result

Data collection

With the men's and women's high jump champion achievements in the Olympic Games as research objects, the collected data are shown in TABLE 1.

Model building

Prediction model for Men's high jump performance:

Using the initial condition $x(14)=1.98$, the following can be obtained: $\begin{cases}\frac{dx}{dt}=r_0\left(1-\frac{x}{x_m}\right)x\\ x(14)=1.98\end{cases}$

Calculate: $x(t)=\frac{x_m1}{1+\left(\frac{x_m1}{1.98}-1\right)e^{-r1(t-14)}}$

Prediction model for Women's high jump performance:

Using the initial condition $x(14)=1.68$, the following can be obtained: $\begin{cases}\frac{dx}{dt}=r_0\left(1-\frac{x}{x_m}\right)x\\ x(14)=1.68\end{cases}$

Calculate: $x(t)=\frac{x_m2}{1+\left(\frac{x_m2}{1.68}-1\right)e^{-r2(t-14)}}$

Fitting using the existing data and the calculated solution is: $x_m1=2.4024$, $r1=0.20934$; $x_m2=2.1173$, $r2=0.15309$

Judging from the above analysis, the limits of the men's high jump score is 2.4024 m and the limits of women's high jump score is 2.1173 m. Based on the prediction model, this study predicts the scores of men's and women's high jump champion of the 30th Olympic Games, and the predicted results are respectively 2.3845m and 2.0707m. And in fact, the all ready known

TABLE 1 : Men's and Women's high jump champion achievements in the Olympic Games(m)

Session	Year	Men	Women
1	1896	1.81	-
2	1900	1.90	-
3	1904	1.80	-
4	1908	1.90	-
5	1912	1.93	-
7	1920	1.93	-
8	1924	1.98	-
9	1928	1.94	1.59
10	1932	1.97	1.657
11	1936	2.03	1.60
14	1948	1.98	1.68
15	1952	2.04	1.67
16	1956	2.12	1.76
17	1960	2.16	1.85
18	1964	2.18	1.90
19	1968	2.24	1.82
20	1972	2.23	1.92
21	1976	2.25	1.93
22	1980	2.36	1.97
23	1984	2.35	2.02
24	1988	2.38	2.03
25	1992	2.34	2.02
26	1996	2.39	2.05
27	2000	2.35	2.01
28	2004	2.36	2.06
29	2008	2.36	2.05

30th Olympic Games results of men's and women's high jump are 2.38m and 2.05m respectively. The prediction data for the men's result is quite consistent with the actual data, and the prediction data for the women's result is slightly different with the actual data. It demonstrates that the block growth prediction model of high jump result has a favorable prediction result and can be used for the prediction of high jump performance, as shown in Figure 1.

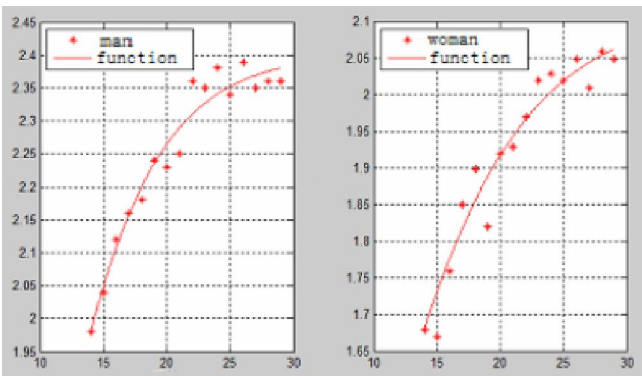

Figure 1 : The growth curve of men's and women's champions achievement

SYMBOL DESCRIPTION

f_1 - The takeoff resistance in the horizontal direction

f_2 - The take-off supportive force in the vertical direc tion

t_0 - Buffer time

v_1 - The horizontal velocity of the hopping foot at last stride in the run-up stage

v_{1x} - Horizontal velocity after the buffering

v_{1y} -Vertical velocity after the buffering

ΔH -The dropping distance of the center of gravity

Δt - Kicking time

v_{2y} - Vertical velocity when the hopping foot is off the ground

F - The reaction force of the ground to the body in kicking stage

CONCLUSIONS

(1) Fosbury Flop is divided into four stages: the run-up stage, the take-off stage, the crossing bar stage and the landing stage. The jump height consists of three parts: H_1 : The height of body center of gravity before vacation. It can be decomposed into h_1, h_2 . h_1 means the height from the ground to the body center of gravity when the knees buffer to the greatest extent since the take-off foot's landing. h_2 means the result that the height of body center of gravity at the take-off moment minus h_1 . H_2 : The vertical distance from the highest point in the vacation to the height of body center of gravity height before the vacation. H_3 : The vertical distance from the body center of gravity to the crossbar in the highest point of vacation. According to the models of the three stages: the run-up, take-off and the crossing bar, it can be approximately established that:

$$H = H_1 + H_2 - H_3 = H_1 + \left[v_2 * \sin a * t - \frac{1}{2} g t^2 \right] + H_3$$

Through the analysis of take-off stage and crossing bar stage, it shows that to accelerate the run-up velocity and the athlete's power to jump in the take-off stage are the main directions to increase H_2 , and to increase the take-off velocity v_2 in the crossing bar stage has an important role in improving the value of H_2

(2) Based on block growth predict model, the past Olympic Games male and female high jump champion achievement data are fitted to obtain the corresponding function. According to the function, predict the results of the next Olympics. The prediction results show that the limit scores of men's and women's high jump are 2.4024m and 2.1173m respectively. And the scores of men's and women's high jump champion in the next Olympic Games are accordingly 2.3845m and 2.0707m, which are highly in coincide with the already known 30th Olympic Games results of men's and women's high jump, that are 2.38m and 2.05m respectively. This indicates that this model is suitable for the prediction of high jump performance.

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