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Study on the analysis and simulation of fosbury flop technique based on the sports biomechanics

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ABSTRACT

Fosbury flop includes three stages: run-up, takeoff and crossing bar. In this paper, the principles of sports biomechanics are implied for the analysis of the three stages in fosbury flop technique, and the dynamic model is established for the three stages of run-up, rake-off and crossing bar. Using Mathematic software to simulate the movement equation, and studying the four affecting factors of a athlete's performance: height, weight, angle of the run-up and speed of takeoff, the multivariate linear regression model was established, thus the rationality of the dynamic model can be verified. This study aims to analyze the rationality of fosbury flop technique and the existing technology and provide reasonable suggestions for the development of the sports and theoretical basis.

KEYWORDS

Sports biomechanics;
Mathematic simulation;
Regression analysis.

INTRODUCTION

Sports biomechanics is a branch of biomechanics, which uses mechanical principle and method to study the theory of the human body mechanical movement, it develops along with the measurement technology, mathematical modeling techniques and computer technology, and thus sports biomechanics will help a lot in the study of sports. And the improvements of the human body link parameters measurement technology and computer simulation technology of biomechanics, study of biomechanics promotes the level of sports biomechanics. This disciplines also promote the development of sports coaches, athletes, sports teachers and sports scientific research personnel, through the practical application of personnel practices, it can providing better prospects for development for its corresponding sports.

On the basis of previous studies on the biomechanics analyses of run-up, takeoff and crossing bar, and based on the results the kinetics model is set up. By using Mathematic software model data are simulated, and then multivariate linear model of higher grades and other related factors is established to explore the influence degree of various factors on the performance, and to verify the rationality of the dynamic model, which will provide a theoretical basis for fosbury lop high jump teaching and training.

MATERIAL ANALYSIS OF EACH PART IN FOSBURY FLOP

We consider the traditional theoretical model of multiple linear regressions. The three parts of un-up, takeoff and crossing bar constitute the main movements of back-style high jump process, the initial parameters of crossing bar is provided by run-up and takeoff, then the corresponding swing of body will help a athlete to cross the bar, and the purpose of which is to achieve the highest jump height through the reasonable action and reasonable position. This paper analyzes the multi-rigid-body link, run-up, takeoff and crossing bar, and a dynamic model is established to carries on the simulation for data.

Moment of inertia in the calculation part for weight, height

Because of the rotation of a athlete's body in process of fosbury style high jump mainly concentrates in the head, limbs and trunk, so in this section, the structure of human body is seen as a rigid body that can be divided into the head, upper trunk, lower trunk, thigh, foreleg, upper arm and forward arm, each of the seven links' moment of inertia of the round shape of frontal axis represented by I_x, I_y is the moment of inertia that is around the sagittal axis, I_z is the moment of inertia that is around the vertical axis. The moment of inertia of hands and feet can be obtain by using the Parallel Axis Theorem to collect the weight into the center of mass and calculating it together with the forward arm and fore leg. the moment of inertia of each link can be obtained according to the empirical data of height and weight on the moment of inertia of dualistic regression equation. The regression equation is shown as formula (1):

$$\begin{cases} \mathbf{I_i} = \beta_{i0} + \beta_{i1}\mathbf{X_1} + \beta_{i2}\mathbf{X_2} + \varepsilon \\ \mathbf{E}(\varepsilon) = \mathbf{0}, \mathbf{Var}(\varepsilon) = \delta^2 \end{cases} \tag{1}$$

In formula (1), I_i is the moment of inertia of a winding axis three axis, X_1, X_2 are the human body weight (kg) and height (CM) respectively, δ^2 represents the variance of regression equation

Parallel axis theorem: if there is any axis that is parallel to the axis which passes through the center of mass, and distance of these two axis is d, the I is moment of inertia produced by the rigid body, as shown in formula (2):

$$\mathbf{I'} = \mathbf{I} + \mathbf{md}^2 \tag{2}$$

In formula (2), I' is the moment of inertia of axis that is relative the axis that through of center of mass m is relative to the quality of the center of mass. The regression coefficients IN Formula (1) can refer to Chinese young men and young women data sheet.

The kinematics analysis and model establishment in the Run-up stage

Figure 1 is an athlete's physical movement condition in the process of run-up.

The kinematics characteristics of running embodies in the step length, step time and frequency, and its kinematic relationship is shown in formula (3)

$$\left.\begin{array}{l} \mathbf{L} = \bar{\mathbf{v}}\mathbf{T} \\ \mathbf{f} = \dfrac{\mathbf{1}}{\mathbf{T}} \end{array}\right\} \Rightarrow \bar{\mathbf{v}} = \mathbf{L} \times \mathbf{f} \tag{3}$$

In formula (3), L stands for step length, T stand for step time and f stands for the frequency, $\bar{v}$ is the average speed of the corresponding steps. If the average speed of the corresponding steps can be calculated by measuring step length and step time, because in the process of run-up the athlete's speed is very fast (instant speed), thus the horizontal velocity for the center of gravity in the run-up process is seen as a as a series of uniform motion. In China, the average step time of a high level athlete's step is 0.216 s, the time of supporting account about 40.7% in average, the time of flight phase accounts 59.3% in average.

In the sprint, Karnel Hoffman points out that men's sprint world level through studying the measured material of

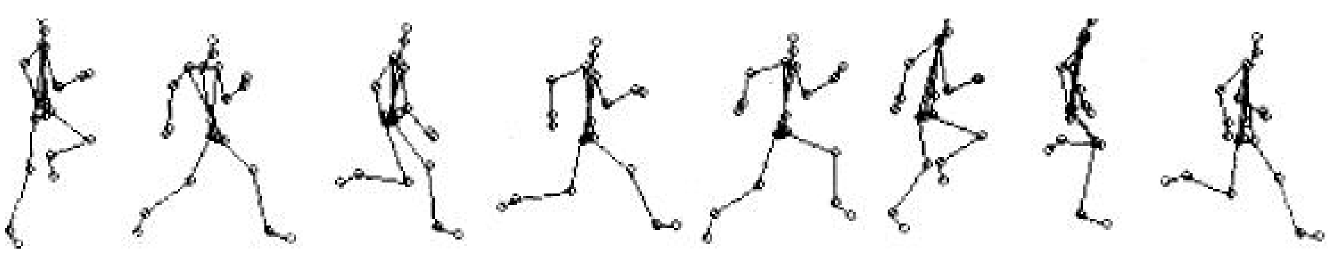

Figure 1 : Stick figure model of human movement during run-up

international major competitions, the calculation of the indexes for the step length and step frequency are shown in formula (4)

$$\begin{cases} \frac{\overline{L}}{h} \ge 1.15 \\ \frac{L_{max}}{h} \ge 1.24 \end{cases}, h \times f \ge 8.1 \qquad (4)$$

In formula (4), $\overline{L}$ stands for the average step length, h stands for the height of the athlete, L_{max} stands for the maximum step length. The indexes in formula (4) are for sprint athletes particularly, so the critical value is selected as the optimum takeoff speed for jump player.

The second stage of run-up is from athletes' last step but three to the last but second step while swinging leg is landing. The aim of this stage is to make the athletes get suitable strength and technology for the speed before takeoff. In the curve running, the supporting leg support knee to bend, the knee joint Angle of the final supporting step is about 120 degrees.

Figure 2 : The curve run-up

Athletes' curve run-up actually is a circular motion of the body center of gravity. when a objects does circular motion, it needs other aspects to provides the centripetal force, force analysis is shown in Figure 3.

According to Figure 3, formula (5) can be obtained

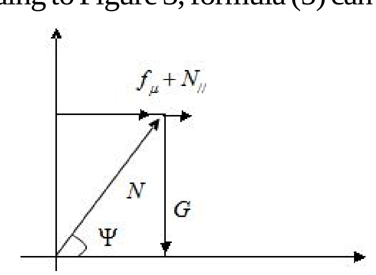

Figure 3 : Stress analysis of tilting objects in a circular motion

$$\begin{cases} N \sin \Psi = G \\ N \cos \Psi = N_{//} \\ \frac{mv^2}{R} = N_{//} + f_\mu \end{cases} \qquad (5)$$

In formula (5), $N_{//} + f_\mu$ stands for the centripetal forceÿ f_μ stands for the friction force of human body on the ground, when the friction force is fixed, the increasing of the run-up speed should reduce Ψ degree, which means that the higher of the run-up speed the bigger tilt degree of the body.

The kinematics analysis and model establishment in the takeoff stage

The preparation of run-up for Fosbury flop begins from the last but second steps, the movement of takeoff stage is shown in Figure 4

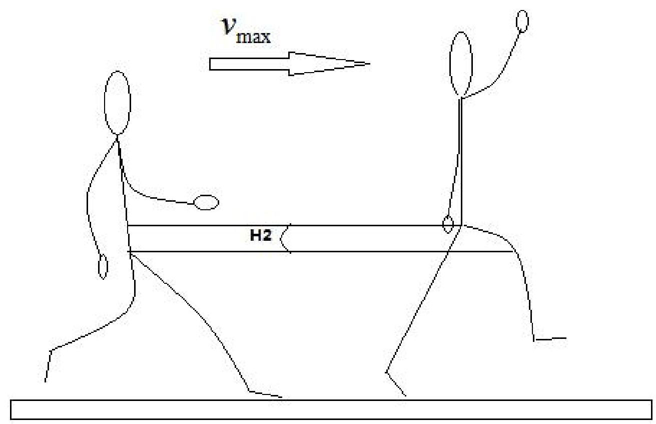

Figure 4 : The movement of takeoff stage

The picture on the left side of Figure 4 is the last step of takeoff, the speed of takeoff is the maximum speed: v_{max}, the picture on the right is the procedure of takeoff, the body center of gravity movements up H2 by supporting leg stretching, the stress analysis of the supporting leg in the process of takeoff is shown in Figure 5:

In Figure 5, Leg bear the forces of force of gravity, force from the ground and physical pressure on the legsÿthe scope of change for angle $\alpha(t)$ during squatting and stretching is [0°ÿ90°]ÿthe scopes of change for $\theta(t)$ and $\varphi(t)$ is relatively small. The force conducted by the ground on legs can be decomposed into vertical

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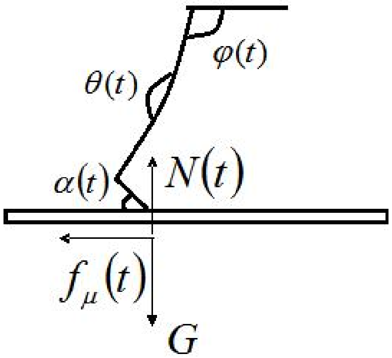

Figure 5 : Stress analysis of the supporting leg

force $F_y(t)$ and horizontal force $F_x(t)$, the roles of the two components are to increase decrease the horizontal velocity and increase the vertical speed, according to the theorem of momentum formula (6) can be obtained

$$\begin{cases} \Delta V_x = \dfrac{\int_0^{\Delta t} F_x(t)dt}{m} \\ \Delta V_y = \dfrac{\int_0^{\Delta t} F_y(t)dt}{m} \end{cases} \quad (6)$$

In formula (6), $\Delta V_x, \Delta V_y$ stand for the variations in the two directions during squatting and stretchingÿ Δt is the supporting time of the ground on legs. According to the conditions of force platform in the horizontal and vertical direction, effects performed by the ground on the supporting legs can be understood, as shown in Figure 6

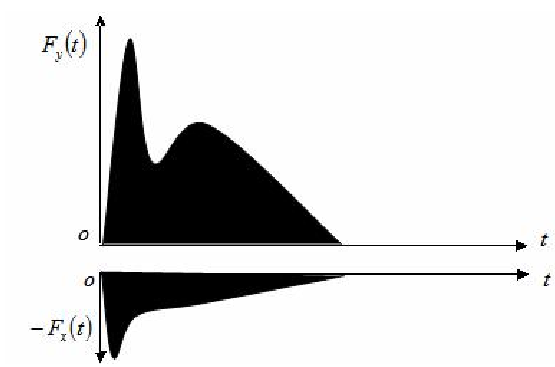

Figure 6 : The stress condition of the force platform in the horizontal and vertical direction

According to Figure 6, the speed of vertical direction keeps increasing, while the speed of the horizontal keeps reducing reflects the essence of takeoff action is to make reasonable horizontal speed loss and the vertical upward velocity increases as much as possible.

At the end of the jump the speed gained by the human body center of gravity is shown in formula (7)

$$\begin{cases} V_{x0} = v_{max} - \Delta V_x \\ V_{y0} = \Delta V_y \end{cases} \quad (7)$$

Angle of the jumping center of gravity is $\arctan\left(\frac{V_{y0}}{V_{x0}}\right)$.

The kinematics analysis and model establishment in the crossing bar stage

At the end of takeoff, J the human body leaves the ground and begins to crossing the bar form his back, the ghost image shown in Figure 7 is the stage of human action for crossing bar.

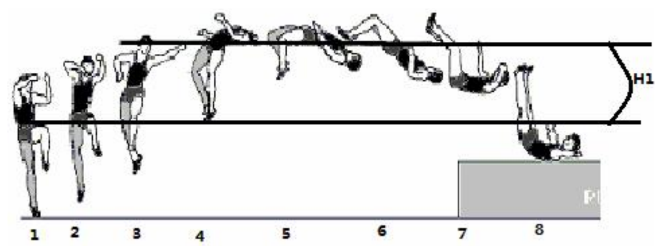

Figure 7 : Crossing bar stage of Fosbury Flop

8 moments of crossing bar stage are collected in Figure 7. The movement around the vertical axis conducted by the athlete in the air accords with formula (8)

$$\left.\begin{array}{l} a(t) = \dfrac{d\omega(t)}{dt} = \dfrac{d^2\gamma(t)}{dt^2} \\ J = \dfrac{1}{2}mR^2 \\ M(t) = Ja(t) \end{array}\right\} \Rightarrow M(t) = \frac{mR^2 d^2\gamma(t)}{2dt^2} \quad (8)$$

In formula (8), $M(t)$ is the torque conducted by the body around the vertical axisÿthe torque changes along with the swing of arms, till the awing angle $\gamma(t)$ of body reaches the180o, the two sides of the body is symmetry, homogeneous disk's formula is adopted for the calculation of the moment of inertia around the vertical axis.

A athlete's arm swing during crossing bar is not just the a relative rotation of the body, it also can improve human body's mechanical kinetic energy. Assuming that the quality of the human arms accounted for 11.28% of total body quality (according to the data of fischer), When the upward instantaneous speed of body center of gravity at the end of takeoff is V_{y0}, centroid speed of the arms' upward swinging is $\sqrt{2}V_{y0}$, then the body processes more energy in the arms upward procedure than that at the end of the jump. The arms' kinetic energy increment expression is shown in formula (9)

$$\Delta \mathbf{E}_{k} = \frac{1}{2}\times 11.28\% \mathbf{m}\mathbf{V}_{y0}^{2} \quad (9)$$

According to formula (9), the kinetic energy increase of human body is 111.28%, that is to say the total energy will reduce by 11.28% if the arms do not swing, if the athlete plans to gain more kinetic energy by swinging arm, conversion relationship between kinetic energy and momentum can be adopted or analysis. When the body's vertically upward momentum increases, its kinetic energy will increase accordingly, in the process of suspension human body is only affected by gravity, the whole body system to a certain extent is in a momentum conservation, through the digestion of the internal energy, the overall momentum of the body can be improved, as long as the extension of the acceleration process can make the change of momentum of growth, so the extending of the arms swing can help to improve the performance of the high jump.

Model simulation

Mathematic trajectory simulation, the simulation image is shown in Figure 8. The purpose of Model simulation is to get players' moving trajectory of the in the crossing bar stage, the moving process of the center of gravity is similar to parabolic motion, the establishment of the equation of motion requires the determination of initial parameters, Zhu Jianhua Chinese elite male athletes is selected as an example to conduct a Mathematic simulation, the image is shown in Figure 8

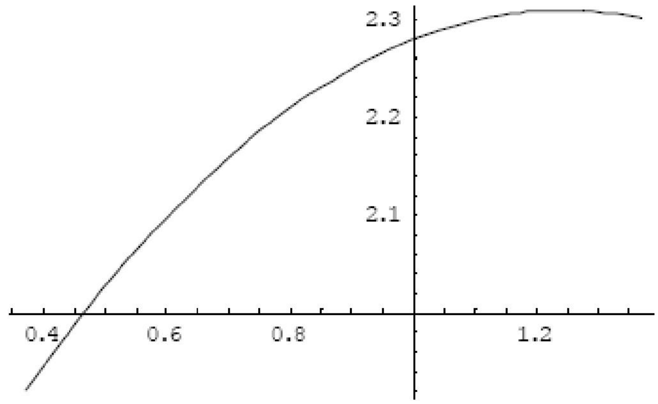

Figure 8 : Simulation diagram of the moving trajectory of the body center of gravity

Figure 8 is the trajectory image of Zhu Jianhua's center of gravity, and which is according with Zhu Jianhua's actual grade 2.35 2.39 m, so the dynamics model can restore the movement through sports biomechanical analysis.

DATA ANALYSIS OF THE RELATED FACTORS

The score closely connects the initial speed processed by human body at the end of takeoff. The following part of this paper will explore data relationship between the

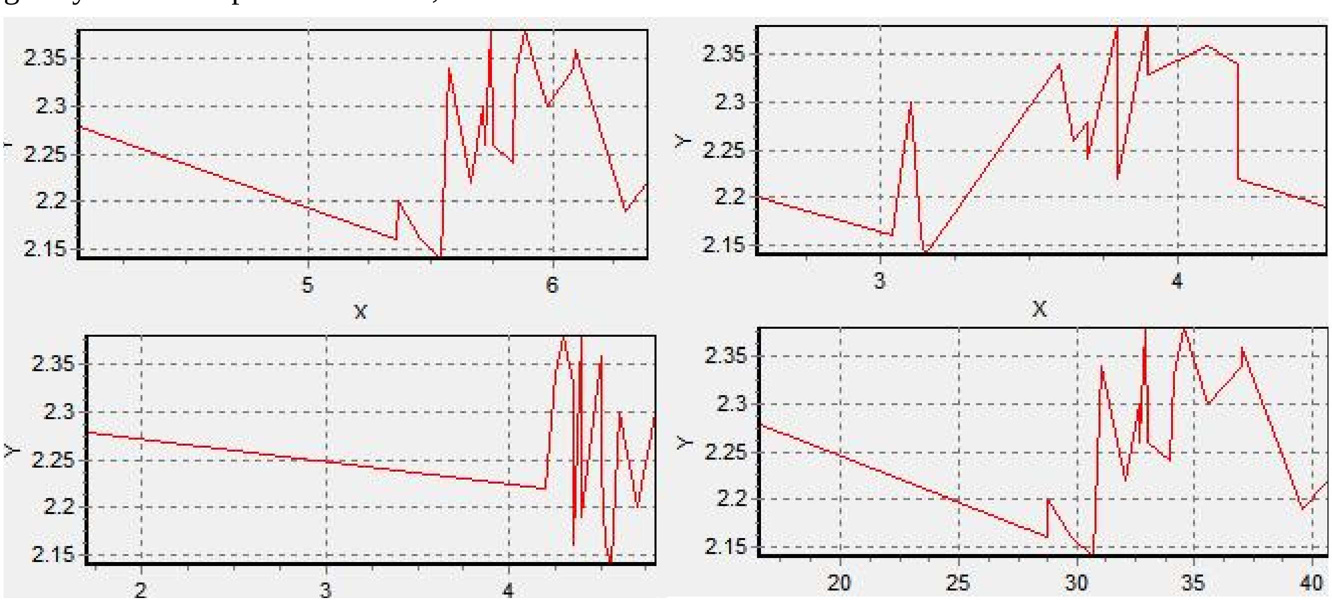

Figure 9 : Change trend of score and speed

high jump result and initial jumping speed l.

By using Forlab, the line chart as shown in Figure 9 is conducted which is related to high jump scores.

The picture on the left upper side in Figure 9 relates to the resultant speed and jumping score, the right upper on is the image of horizontal velocity and jumping score, the left lower one is the image of vertical speed and score, the right lower one is the image of squared velocity and score, from four image can be seen that the correlation between jumping speed and the score is not very close, formula (10) is four quaternary linear regression equation of jumping score and the four kinds of speed

$$\mathbf{H = -7.3137 - 0.2904v^2 + 4.64773v - 0.7333v_{//} - 1.1323v_{\perp}} \quad \mathbf{(10)}$$

In formula (10), H stands for the jump score, v stands for the resultant speed of jumping, $v_{//}, v_{\perp}$ stand for the horizontal velocity and vertical velocity respectively. According to formula (10), H is positively relates to resultant velocity v, which processes the largest sensitivity, besides the vertical velocity also affect the jumping score.

Statistical parameters in formula (10) are as follows:

Residual sum of squares=0.0645; sum of squares of deviations =0.1058;

Multiple correlation coefficient =0.6252; variance =0.1795

According to statistical parameters, the goodness of fit for the multiple linear regressions is good, which reflects that the influence of resultant speed and vertical speed on the jumping score is very big.

CONCLUSION

For fosbury flop technology research, the human body can be seen as a multiple rigid body model, by studying the rigid motion situation, the actual movement of the human body can be reflected; In the process of takeoff, the fully stretching of trunk can improve vertical speed, and increase the effect of human impulse at the same time alsoÿafter the jump, in order to increase the moment of inertia for the body to cross the axis the body, a athlete should make full use of the arm swing effect; Trajectory simulation of Zhu Jianhua is conducted through dynamic model, and the rationality of the guidance of biological movement mechanics on this movement is verified; Through data analysis and the establishment of the quarternary linear regression equation, the following conclusion is got that the jumping speed and vertical speed influence the jumping score in a deep degree, it also validates the importance of the jumping angle; Through sports biomechanical principle, this paper makes a reasonable analysis on fosbury flop and reduces the movement perfectly.

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