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The statistical analysis based on biomechanical parameters of triple jump

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ABSTRACT

The triple jump makes the athlete's body to attach the greatest distance by the interaction between the athlete's internal force and the ground. The high level training of the triple jump is not simply running and jumping. In the paper, the biologic theory is adopted, and the dynamic analysis of the three triple jumps is analyzed, then the rationalization proposals which promote the result by analyzing the results. Moreover, the theory is used to compare the triple jump results of athletes domestic and overseas to confirm the rationality of the theory and existing technology development.

KEYWORDS

Biomechanics;
Mathematical model;
Triple jump;
Statistical analysis.

INTRODUCTION

The two purposes of studying the biomechanics: The first purpose is to improve the athletic ability and the ability includes the athlete's competitive level and the national fitness level; the second purpose is to prevent the sport injury. The biomechanics, which is an important part of the sport science, plays a significant role in the five aspects of improving sports techniques, improving training methods, design and reforming the sports equipments and preventing the sports injuries and injury rehabilitation.

As for the triple jump technology and the study of mechanical analysis by many people, the technical improvements achieve the better effects with the help of the research results. The parameters of the triple jump technique which is combined biomechanics with the applied mathematics is less, then the studies of the triple jump techniques based on the mathematic model are necessary.

In this paper, biochemical theory is used to carry on the detailed mathematic analysis on the technique parameters of the three jumps in the triple jump process and the statistical results based on the biomechanics analysis to confirm the reason on data differences between the national and world triple jump athletes, provide the reasonable proposals for the training of the item, and provide the theoretical basis of improving the performance for athletes.

THE MODEL OF HUMAN BODY

The gravity center of human body

There is a correlation exists between the quality of the athletes'each link and his total body weight W the height H the binary linear regression equation between the quality of each link and W or H according to the sample fitting in the national database on human research, Just as shown in the formula 1:

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$$P = \beta_0 + \beta_1 W + \beta_2 H \quad (1)$$

In the formula (1): P refers to each link quality of human body, the unit is kg;

The regression coefficients $\beta_0, \beta_1, \beta_2$ and the regression parameters R^2, δ is shown in the TABLE 1:

TABLE 1 : The binary regression coefficients of Chinese human link's quality on body weight W (kg) and the height H (mm)

Link Name	Sex	β_0	β_1	β_2	R^2	δ
Head and Neck	Male	29.9540	0.0400	0.0001	0.4350	0.3940
	Female	1.6065	0.0240	0.0009	0.4590	0.2690
Upper Torso	Male	-5.0010	0.1110	0.0050	0.5660	1.0860
	Female	-9.6720	0.0030	0.0077	0.5590	1.2010
Lower Torso	Male	2.2860	0.2980	-0.0027	0.7290	1.2120
	Female	-9.4400	0.2610	0.0055	0.7900	1.0820
Thigh	Male	-0.3230	0.0300	0.0001	0.5980	0.1900
	Female	1.1210	0.0390	-0.0011	0.7440	0.1370
Leg	Male	-0.2770	0.0160	0.0001	0.5820	0.1050
	Female	-0.2880	0.0140	0.0001	0.7200	0.0620
Upper Arm	Male	-0.4240	0.0030	0.0004	0.7800	0.0250
	Female	-0.0030	0.0020	0.0001	0.2480	0.0460
Forearm	Male	-0.0930	0.1520	-0.0004	0.7560	0.6000
	Female	-3.1930	0.1450	0.0022	0.7550	0.6450
Hand	Male	-0.8340	0.0610	-0.0020	0.7350	0.2550
	Female	-2.7020	0.0420	0.0018	0.7370	0.2340
Foot	Male	-0.7150	0.0060	0.0007	0.8130	0.0450
	Female	-0.6840	0.0100	0.0006	0.4840	0.1220

In the image resolution of the athletes, the human body gravity coordinate is solved according to the resultant moment theory, just as shown in formula 2:

$$\begin{cases} X_c = \sum_{i=1}^{9} \frac{P_i}{W} x_{ci} \\ Y_c = \sum_{i=1}^{9} \frac{p_i}{W} y_{ci} \end{cases}, \sum_{i=1}^{9} P_i = W \quad (2)$$

In the formula 2: (X_c, Y_c) expresses the athletes' body gravity coordinate, $(x_{ic}, y_{ic})(i=1,2,3,\cdots,9)$ expresses the centroid coordinate of each link, and P_i is each link's quality.

The rotation Law of each link in human body

The moment of inertia is the physical quantity of the inertia of the rotating objects. The greater the rotational inertia, the more difficult changes in the rotation state. In the study of the technique of triple jump, it is necessary to measure the rotation of each link of the body. Generally, the link is regarded as the collection of the particle, then the forms of expression of the moment of inertia of particle just as formula (3) :

$$I = \lim_{\Delta m \to 0} \left(\sum \Delta m r^2 \right) = \int r^2 dm \quad (3)$$

In the formula 3, Δm refers to quality infinitesimal of each link, r refers to the distance of the axis of rotation of the link.

The product of moment of inertia and angular velocity is angular momentum. In general, the moment of inertia is considered to be change in the motion process, and it is relative to its own essence. For example, the state of human straightening triple jump action in the triple jump process is shown in the Figure1:

Figure1 : The lengthwise relative moment of the straightening jumps

The Figure 1 expresses the whole angular momentum of the human body $M=I\omega$, the upper link of the human body rotates the axis according to angular momentum $M_1 = I_1\omega_1$, the lower link of the body rotates the same axis according to angular momentum $M_2 = I_2\omega_2$, in the state, the aggregate momentum of human body satisfy the formula (4)

$$M = I\omega = M_1 + M_2 = I_1\omega_1 + I_2\omega_2 \quad (4)$$

The human body is the motor system of each link, the function of the human body is divided into internal force and external force. As for the link, the force of the link on the other link can be considered to be the external force of this link, and its movement can meet the law of the angular momentum, just as shown in the for-

mula 5:

$$\Delta M = \sum F \times r = I_2\omega_2 - I_1\omega_1 \quad (5)$$

In the formula 5, as for the identified link $I_1 = I_2$, the theorem of moment of momentum is the peak torque of the force on the link equals to the variation of the angular momentum.

Tion of biomechanical analysis

The good approach is the precondition of successful take-off, and the successful take-off is the result of better approach. Only with the close coordination between the approach and take-off is the complete efficiency jumps. In all kinds of the jumping sports, the process of take-off exists negative effects. When take off is completed, the horizontal velocity of the human motion reduces 10% on average. However, the speed of vertical direction is increased. When the approach is finished, the take-off is shown in the Figure2:

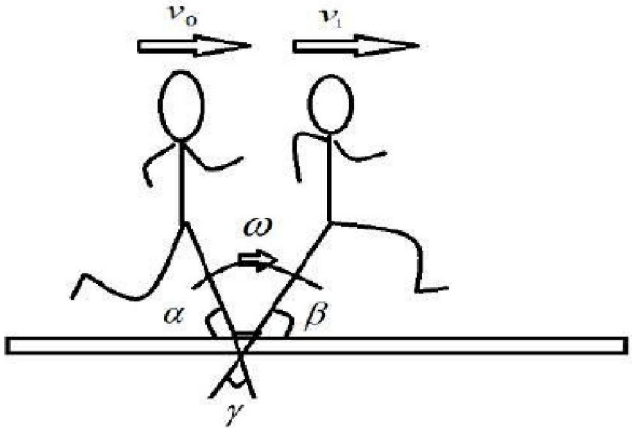

Figure 2 : The diagram of take-off after approach

α in Figure 2 expresses the touchdown angel of the swinging leg after approach, β expresses the take-off angel of the take-off after the approach. However, γ=(180–α–β) expresses the variable quantity of the angle of supporting leg in the process of the take-off, which is called the fan feet. The process of take-off the process which makes the supporting leg rotate angel γ with the speed of $\omega(t)$ by the final velocity v_0 of approach speed. The process makes the horizontal velocity chang into . In the motion process, the body horizontal motion satisfy the theorem of momentum, and the supporting leg meet the angular momentum theorem, just as shown in Figure 6:

$$\begin{cases} \int F(t)_{//}\, dt = W(v_1 - v_0) \\ \int F(t)_{\perp}\, dt = W(v_1 \tan\beta + v_0 \tan\alpha) \\ \int F(t) r dt = \Delta M = I\Delta\omega \\ \Delta\omega = \dfrac{v_1 \sec\beta - v_0 \sec\alpha}{r} \end{cases} \quad (6)$$

$F(t)_{//}$ in the formula 6 expresses the ground's horizontal force in human, $F(t)_{\perp}$ expresses the ground's force on human body in the vertical direction, r expresses the radius of the rotation of the supporting leg, $\Delta\omega$ expresses the angular velocity before and after take-off.

It can be known from the formula 6, the less the time of the ground force on the human body, the smaller the loss of horizontal velocity; the greater the speed of approach, the greater horizontal speed of take-off. From the direction of the ground force on human, we can see the loss of the horizontal speed is necessary. However, in the process of supporting leg striking the ground, the vertical velocity before the take-off is down and the vertical velocity after the take-off is upper. The take-off can promote the speed of vertical direction and the promoting effect can be related to the size and orientation of the force. It can be seen that the increases of the angle of take-off and the decreases of the ground angle promote the height of take-off, and vice vera, the horizontal velocity can be promoted.

The biochemical analysis of flight phase in hop

The purpose of the take-off is to flight when the human keep certain horizontal speed and acquire certain vertical speed and achieve the maximum degree of the distance. The flight of hop in the first jump of the triple jumps is shown in the Figure 3,

In the Figure 3, v_1 expresses the initial velocity of the take off; $h(t)$ expresses the displacement of the gravity center of human body in the vertical direction at t time. The external force exerts on the human in the process of the flight is the air resistance and gravity. Compare with the air resistance, the small human gravity can be negligible, and then the motion of gravity center of human body in the horizontal and vertical direction can satisfy the newton's second law. Thus, the motion of the flight phase can satisfy the formula 7,

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$$\left.\begin{aligned} s(t) &= v_1 t \\ h(t) &= v_1 \tan\beta - \frac{1}{2} g t^2 \end{aligned}\right\} \Rightarrow s(t) = \frac{2v_1 \times (v_1 \tan\beta)}{g} \qquad (7)$$

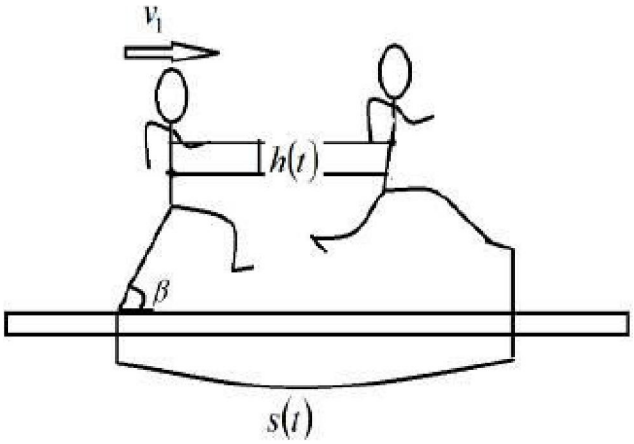

Figure 3 : The end of take-off of the hop top and diagram of flight

In the formula 7, is the acceleration of gravity.

It can be known from the formula 7, if the maximum value of $s(t)$ is to be obtained, the angel of v_1 and β should be increased at the same time. One is increasing the horizontal speed and the other is increasing the vertical speed. Just as the saying ' no height, no distance', the athletes pursue the speed type, and the height is put in the second level to pursue the maximum horizontal speed. In the process, the speed of two directions can achieve the effects of complementation. Testing and verifying the athletes' data pursue the maximal angle of take-off of horizontal displacement. Of course, the vertical shift of the gravity position is controlled by human in the flight phase, that is to say, the trunk is pressed down, and to some extent, the time of flight is increased to provide more operating time for the horizontal displacement.

The biochemical analysis of step jump

The beginning of the step jump is the take off leg in the hop touch down on the ground, the athlete needs to drop the body from high to low in the process. The human body is exerted counter-acting force by the ground in the failing process, then the body flight again by the interaction of the human internal force and the ground reaction force, and the movement situation is shown in the Figure 4,

In the Figure 4, α' is the touchdown angle of ending the hop, β' is the angle of take off in the step jump, and γ' is the angel variation of supporting leg in the step jump, which is also called the fan angle of the step jump. Its motion situation satisfy the formula 6 and formula 7.

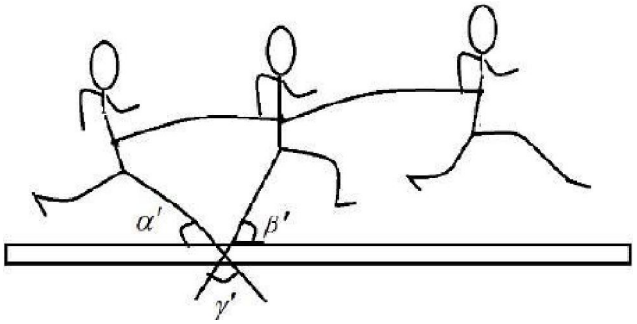

Figure 4 : The end of hop and the diagram of the leap

By analyzing the kinematics formula, increasing the horizontal displacement of the step jump sets about the horizontal speed of flight of the step jump and the time of the flight. In the premise of reducing the minimum horizontal velocity, he time of flight need to be extended. Because the body produces the great braking impulse from the height to the ground, when is less than the 90 degree, the ground produce the braking function on the human impulse; when α' is more than 90 degree, the ground produces the dynamic effect on the momentum of human body, and the time of the braking impulse is reduced to make the center of gravity shift into the parallel position of supporting leg. When the center-of - gravity position falls in the front fulcrum, β' is reduced to increase the horizontal velocity. In the process of the flight, the gravity center of human body was downward to increase the flight time to increase the horizontal displacement of human body.

The biochemical analysis of jump

The third stage of the triple jumps is called the jump stage. The stage between take-off leg touching down the ground in the step jump and the athletes' two legs touching down on the ground at the same time is called the jump stage. The third jump after the two jumps, the horizontal velocity of the athletes had dropped significantly comparing with the previous stages. But in order to achieve the greatest distance of the horizontal velocity, the main task of the third stage is to make full use of speed of horizontal velocity and improve the vertical speed. The motion speed is shown in Figure 5,

The Figure 5 shows the process of the third jump,

and the process comprises a take-off process, a leg up off the process and the process of two opposite bodies.

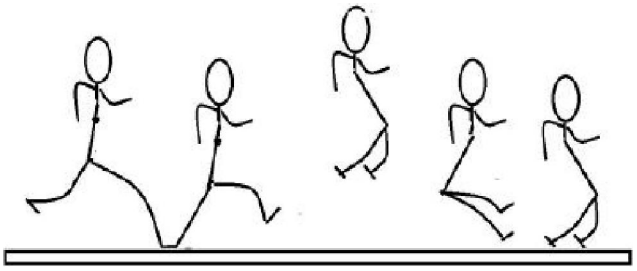

Figure 5 : The diagram of the third jump process

The take-off process satisfies the formula 6, the process of flight after take-off exists the positive swing of the take-off leg followed the swinging leg. In the process, the positive swing of the swinging leg lead to the motion lag of the gravity center of the human body so that the relative movement of standing up process exists. According to the formula 4, the process which comes forward to meet the opposite movement throughout the body part of the law of conservation of angular momentum. Accord to the formula7, it is necessary to lower the gravity center to prolong the flight time to achieve the maximum of distance, that is to say, the gravity center is to be raised to reduce the time of the falling gravity center. The secondary torso is accelerated when both feet touch down the ground to make the heel is the final body landing on the ground.

THE KINEMATICS PARAMETER ANALYSIS OF THE TRIPLE JUMP

The average kinematics parameter analysis of the Li Yanxi and Zhu Shujing, who is the nationwide famous triple jumpers and the Edwards, who is the record holder and other elite athletes in each phase can be collected.

The data analysis of approach speed

The high correlation results exist between the specific performance of approach speed and the final long jump performances, the TABLE 2 is comparison Table of the results.

According to the formula 3, the three-meter approach result is the independent variable and the final results of the triple jump is the dependent variable, then the least square method is used to obtain the fitted equation just as shown in the formula 8,

$$\hat{y} = -0.8794 + 1.759\,\hat{x} \quad (8)$$

TABLE 2 : The comparison of the results between triple jumps and the three-meter approach

Athletes	The final results of triple jump(m)	The results of three-meter approach(m/s)
Edwards	18.29	10.90
The world elite athletes	17.48	10.43
Li Yanxi	17.12	10.24
Zhu Shujing	17.03	10.18

The statistical parameters of the fitted curve are as follows:

Residual sum of square =0.0004; Sum of squares of deviations =0.9882;

Multiple correlation coefficient =0.9998; Variance =0.0004;

From the above results, the high correlation exists between the final results and the approach results. As long as the approach results accelerate the 1m/s and the final result of the triple jump will accelerate the 1.759m.

The data analysis of the hop

The high correlation exists in the ground speed, liftoff speed, reaction time, angle of projection of body gravity center and the final results of triple jump. The TABLE 3 is the comparison table shows biochemical parameters of the hop and the final results of the Chinese and Foreign triple jump.

TABLE 3 : The comparison of hop technique parameters

The athletes	Final Results(m)	Ground Speed	Liftoff Speed	Reaction Time	The angle
Edwards	18.29	9.92	9.89	0.10	15.3
The world elite athletes	17.48	9.77	9.51	0.11	15.5
Li Yanxi	17.12	9.69	9.34	0.12	16
Zhu Shujing	17.03	9.58	9.20	0.12	16

As can be seen from TABLE 3, it is positive relativity between the ground speed or the liftoff speed and the final results of the triple jump; it is negative relativity between the action time or the angle of projection of body gravity center and the final results. The increasing ground speed, the reduction of reducing the loss of speed, the reduction of the action time and the reduc-

tion of angle of body gravity center help to improve the final results of the triple jump.

The study shows that the ideal ratio of the elite male athletes is 36:30:34; as for the athlete of high approach speed, the ideal distance ratio is 35:30:35. From the TABLE 4, we can not see the proportion brings out better achievements, the scope of the takeoff is between 35% and 38%; the scope of the step jump is between 29% and 30%, and the scope of the third jump is between 33% and 35%. The athletes can adjust the biomechanical parameters in the movements according to the best ratio.

CONCLUSION

Improving the approach speed helps to improve the jumping performance; reducing the loss of horizontal speed in the hop and step jump phases help to athletic performance; during the step jump and the jump phases, the gravity center stride down to extend the athlete's flight time to help to improve the overall performance; In the third jump phase, the first slow standing motion of the opposite movement and the fast motion hem torso can be controlled to help to extend the flight time; In the third stage, the second slow sanding motion of the relative movement should be quick to prevent leaning back; Increasing the ground speed and liftoff speed helps to improve the performance; Reducing the flight angle helps to improve the initial speed of weight transfer to improve the performance;Strengthening athletes theoretical knowledge, so that the theory guide practice to create more achievements.

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