Research Journal of Applied Sciences, Engineering and Technology 5(5): 1589-1593, 2013
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: July 17, 2012 Accepted: August 28, 2012 Published: February 11, 2013

Analysis of Mechanical Model on Factors Influencing the Long Jump Result Under the Perfect Condition

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Abstract: The research uses mechanics ideal model to analyze the world excellent broad-jumper performance and relevant kinematics parameter, finds the mechanical factors that help the broad-jump athletes get the best results, thus provides support for relevant theories of broad-jump teaching and training and provides basis for future broad-jump technology development and training. To build mode for the outstanding broad-jumper performance and the related parameters on the basis of documental materials. Through the related parameters kinematics analysis on athletes long jump performance, it is considered that improving the utilization rate of speed jump is the key to guarantee the takeoff effect and obtain ideal achievement, increasing the utilization of the run-up speed, appropriately increasing vertical speed and increasing the prancing Angle are the important ways for the long jump athletes to achieve best results; Only if the athletes use effective means for targeted training, they can ultimately improve the level of long jump.

Keywords: Influencing factors, long jump, mechanics model

INTRODUCTION

The long jump competition in ancient Olympic Games began from 780 B.C. as an event in five competitions. The first world record of male long jump was set by an Englishman F.G. Gucci with the competition result of 5.80 m. It was not until 1875 that Raul from Iceland passed the mark of 7 m for the first time. Since the 1890s, extensive researches into the jumping skills have been carried out with Europe as the research center while the study of the run-up speed was ignored thus leading to the result that the long jump technology had not been greatly improved (Di and Li, 1987). With the development of sports technology, systematic and extensive researches into the theories of long jump technology have been made from the angle of biomechanics, anatomy and psychology thereby improving the performance of long jump continuously. The world record set on the World Athletics Championships held in Tokyo in 1991 by the American athlete, Powell is held till the present (Zhao, 2001).

As a complex and key link for the long jump technology, take-off is the turning point for athletes from horizontal motion to projectile motion and is an important factor determining the long jump performance. When taking off, the athletes should swing legs as fast as possible, shorten the take-off time, increase the vertical speed, improve the usable quantity of the run-up speed and choose the proper take-off angle. For the researches into the take-off technique in kinematic aspect, most experts at home and abroad make the analysis from the aspects of angular velocity of body forward spin, trunk rotation, swing skill, step length, link and joint angle and velocity, etc., (Wang, 2002).

Shuyong Feng believed that the last three steps (especially the last two steps) had an important influence on the stability before jumping for the middle-level male long jumper (Feng, 2001). The smaller of distance among the last three steps is, the less losses of speed before jumping, this is conducive to get higher initial speed. The changes of cadence and the length of step affect the speed of the body's gravity directly, and the last step length also affects the distance between the body's gravity and the springboard. For most athletes, the last step length is shorter than the penultimate step. It does not the athletes run in rhythm consciously, but the random action which informed in order to speeding and preparing jump fully (Yao and Zhang, 1980). Some researches show that, when the plate angle is increasing, the resistance and loss of speed are both decreasing, with the body's gravity moving forward quickly, the loss of speed when jumping become less. Strictly, the plate angle represents the position of body's gravity only; it cannot fully represent the status of the body. Because the body's condition is constructed by the position and speed of gravity (Wang, 1980). Jiana proposed that the buffer margin when jumping is an indicator which can evaluate the buffering capacity and the technology of jumping. The capacity of buffering is important factors which decide the effectiveness of jumping. Popov also provided some quantitative indicators: to jump 8.50-8.60, in needs the auxiliary speed reach 10.6-10.8 m/s, the vacated angle 19-20°, the knees buffer angle around 143°. There are a lot of researches on the jump buffer margin either in domestic or abroad, although the conclusions are different, they all emphasize the role of buffer (Igor *et al*., 1984). When the air resistance is ignored, the track of body's gravity that at the stage of vacate is a parabola, so the vacant distance which occupy the largest proportion in the long jump results can calculated by the projectile formula, among this, the initial speed and the flight angle are all key factors. Yiyuan Cai in China measured the data of athlete Valli who is in Romanian, and concluded that the off angle is 21.15°, the gravity speed of jumping away from plate is 8.679 m/s. In summary, the off angle is generally between 20° and 22°. The purpose of jumping in long jump is to try to keep the maximum horizontal velocity and meanwhile to try increase the vertical speed. Does it can't loss horizontal speed when jumping? It is inevitable to loss horizontal speed, because the body's gravity would generate some changes when jumping, which have a certain angle with the direction of movement. Hong Shi based on the study of middle-level male athletes in long jump and concluded that: "when the loss of speed is between 10 and 15% at the stage of jumping, the track which is determined by corresponding initial speed and the off angle could provide the athletes with a larger projectile and an appropriate jumping height (19.21-2.26°)".The statistical results show that: the loss of speed which at the stage of jumping has not significant correlation with the results of long jump. When it shows a negative correlation with the sub-speed of horizontal, it also shows a positive correlation with the sub-speed of vertical. Ba Qiu achieved a conclusion which is opposite to the majority persons': "If there is no loss of speed, it is impossible to complete done well or even need to recourse to brake (Tao and Xuejun, 2008).

What factors are related to the long jump performance? The complete technology of long jump consists of run up, take off, jumping and landing (Xin, 2010). The article makes the mechanical analysis of the performance and relevant take-off parameters of the world elite male long jumpers by making use of the mechanical model with the aim of figuring out the mechanical properties of male long jumpers in the process from take off to landing so as to provide theoretical basis for pertinent training of athletes in the future and exerting fundamental guiding significance on improving long jump level of athletes.

RESEARCH OBJECTS, METHODS AND RELEVANT TECHNICAL MEANS

Research objects: Take the performance and relevant take-off parameters of the world elite male long jumpers as the research objects.

Research methods:

Documentary data method: Consult the athletic long jump competition data, long jump influencing factors analysis, sports biomechanics, computer programming and other monographs in related aspects and relevant literature; understand the current influencing factors of long jump performance and empirical status quo and research methods from which the technical difficulties and keys of relevant researches can be found.

Mathematical statistics method: Make statistics and analysis of the performance data in the material.

Relevant technical means: Make analysis of the long jump performance and relevant data by applying the biomechanical principles and formulas, compile the data by the functions and formulas in Excel 2003 and make calculation and measurement of each parameter constituting the long jump performance.

RESULTS AND ANALYSIS

Analysis of the long jump process: No matter what flight part is adopted by the athletes in long jump, the track of gravity centre of the body formed after take off, namely, the projectile motion, will not be changed. The initial velocity of body jumping is Vo, the angle of take off is α, the original point O is the take-off point, the x-axis of OC is the horizontal line of take off, as the body takes off from a certain inclination angle after running up to point O, to assume that the gravity center is at the point B at this moment, regardless of the gravity action (and ignoring the air resistance action in the whole long jump analysis process), the gravity center of the athlete body should in uniform rectilinear motion along the direction of OB; however, due to the gravity action, the gravity center of the athlete body is actually in projectile motion; to assume that the gravity center of the body reaches point A when the feet are landing on the ground, the body gravity center was in curvilinear motion in the previous process. Right after landing at point A, the athlete bend knees, the pelvis moves forward and two arms swing forward thus making the body pass the landing point quickly and the gravity center falls down to the landing point C fast, the whole process is shown in the Fig. 1.

The length of long jump is the horizontal distance from the take-off point to the landing point. I have divided the long jump process into three stages, then the long jump performance (L = OC) is composed of the following three stages:

L1: (The first stage: take off, the motion track is from O to B), that is, the segment OE is the horizontal distance from the projection point of gravity center to the backline. There must be a certain angle (smaller that 90°) between the legs and the ground when taking off. L1 is determined by the height of the athlete and the take-off angle together.

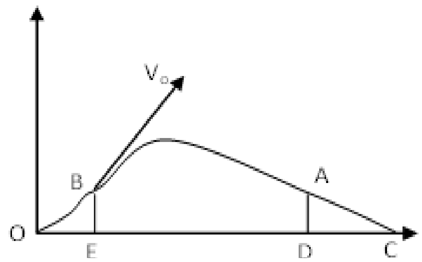

Fig. 1: Human body motion track

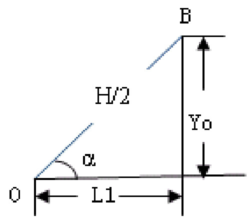

Fig. 2: Take of trajectory

L2: (The second stage: jumping, the motion track from B to A), that is, the segment ED is the aero horizontal distance of the gravity center in the jumping process.

L3: (The third stage: landing, the motion track from A to C), that is, the segment DC is the horizontal distance from the take-off horizontal line to the landing point of the gravity center.

Then the long jump length L can be represented as: L = L1 + L2 + L3.

Establishment of the mathematical model:
Assumptions:

1. The force action point of athlete is at the gravity center and the gravity of the human body is at the cross section of 1/2 height of the human body.
2. Regardless of the air resistance in the whole motion process, that is, the gravity center is stressed only by the gravity in jumping.
3. Consider the initial speed of the run up as the initial speed of body jumping.
4. In the second stage (the jumping stage) and the third stage (the last stage of the gravity center from A to C), the gravity center is always in projectile motion. The gravity center is in rectilinear motion in the third stage actually. The above assumptions are made for the sake of convenience.

Variables and parameters: Vo refers to the initial speed of body jumping; α refers to the take-off angle of jumping; H refers to the height of athlete; Vx refers to the horizontal speed; record the take-off time as Moment 0, Yo refers to the vertical displacement of the gravity center at this moment.
The first stage is shown the Fig. 2 as follows:

The horizontal distance L1 of this stage is determined by the athlete height and the take-off angle:

$$L1 = \frac{H}{2 * \cos\theta}$$

The second stage and the second stage:

As the assumption (4) suggests that the gravity center is in projectile motion, in accordance with the parallelogram law of mechanics of motion, the motion of human body can be decomposed into two sub-motions in orthogonal directions (the horizontal direction X and the vertical direction Y) which are mutually independent.

On the horizontal direction: the uniform rectilinear motion:

$$Vx = Vo * \cos\alpha \tag{1}$$

$$L2 + L3 = Vo * \cos\alpha * t \tag{2}$$

On the vertical direction: vertical parabolic motion with the initial speed being:

$$Vo * \sin\alpha$$

$$Y = Yo + Vo * \sin\alpha * t - 1/2 * g * t^2 \tag{3}$$

(Yo is the height of gravity center when taking off: Yo = H/2* sinα)

When Y = 0, the athlete can complete the whole long jump process, then formula (3) can be solved:

$$t = (Vo * \sin\alpha / g) * (1 + \sqrt{(1 + 2 * g * Yo / Vo^2 * \sin a^2)}) \tag{4}$$

Substituting formula (2) with formula (4) gets:

$$\mathrm{L2} + \mathrm{L3} = \mathrm{Vo}^2 * \cos\alpha * (\sin\alpha / g) * (1 + \sqrt{(1 + 2 * g * Yo / Vo^2 * \sin a^2)})$$

From L = L1 + L3 can get:

$$\mathrm{L} = \mathrm{H}/2 * \cos\alpha + \mathrm{Vo}^2 * \cos\alpha * (\sin\alpha / g) * (1 + \sqrt{(1 + 2 * g * Yo / Vo^2 * \sin a^2)}) \tag{5}$$

List 1 of the technical parameters of long jump of world-class athletes, just as follow Table 1:

The performance got by substituting the model with relevant data of the following four athletes by using formula (5): List 2, just as follow Table 2.

By comparing the ideal model performance and the actual performance, the former one is better than the latter one because of the feet shrinking after touching

Table 1: Relevant technical parameters of world elite athletes

Athlete name	Performance	The run-up speed of the last 10 m (m/s)	Initial speed of take off (m/s)	Horizontal speed (m/s)	Vertical speed (m/s)	Take-off angle (°)
Huang Geng	8.38	10.70	9.85	9.25	3.39	20.1
Beamon	8.90	10.70	9.60	8.76	3.96	24.2
Lewis	8.91	11.25	9.71	9.11	3.37	20.3
Powell	8.95	10.87	10.2	9.27	4.20	24.6

Table 2: Model data

Athlete name	Model performance (m)	Actual performance (m)	Error (m)
Huang Geng	8.75	8.38	0.37
Beamon	9.12	8.90	0.22
Lewis	9.13	8.91	0.22
Powell	9.21	8.95	0.26

Table 3: Measurement data unit: meter (the initial speed is 9.5 m/s)

Take-off angle	Height: 1.57	Height: 1.67	Height: 1.76	Height: 1.94
16 (°)	6.74	6.94	7.12	7.46
19 (°)	7.43	7.62	8.00	8.11

the ground and the gravity center falling down to the landing point and beginning to move in rectilinear motion and the influence of air resistance in the third stage of long jump. The distance L3 in the third stage is determined by the athlete height and the angle between the athlete and the ground instead of moving in the projectile motion according to the model assumption; the gravity center of the third stage in the model moves a certain distance in the horizontal initial speed thus causing L3 larger and the whole long jump performance better.

DISCUSSION ON THE FACTORS INFLUENCING THE LONG JUMP PERFORMANCE

In it can be known that the distance L of long jump is related to the run-up speed, the height and the take-off angle. The analysis was made successively:

The relationship between height and long jump performance: The performance will be different due to different gravity center heights of different athlete heights in spite of the same initial speed and the same take-off angle. The assumption (1) suggests that L1 will be larger as the gravity center height is bigger because of the height and long leg of athletes. It can be known from the expression L that L increases as H increases, just as follow Table 3.

It can be seen from List 3 that:

Athletes of different heights will make different long jump performance in the same initial speed and the same take-off angle; the larger the height is, the larger will be the long jump performance.

The relationship between the run-up speed and the long jump performance: The main factors determining the performance of long jump is the initial speed of take off which in turn is determined by the run-up speed. Therefore, people focus their attention on developing the run-up speed so as to achieve higher take-off speed and longer jumping length. However, the higher run-up speed increase the difficulty of effective take off and relatively large take-off angle which are right the key to the success of long jumpers. It can be concluded form the mechanics that:

$$L2 = Vo^2 * \frac{\sin\alpha}{g}$$

L2 is determined by the initial speed VO and the take-off angle α. It is ideal to increase VO and α simultaneously in theoretical sense yet it is impossible in practical situation. Because the two variables influence each other mutually, the length of jumping is affected not only by the initial speed of take off but also by the take-off angle and the initial speed is determined by the run-up speed, Just as follow Table 4.

It can be seen that the larger the run-up speed is, the better will be the long jump performance. Vo is determined by the run-up speed and to increase the absolute speed ability is the basis for the run-up speed of long jump. Compared with the 100 m performance of Beamon, Powell and Lewis, the differentials reach 0.62s, 0.37s and 0.96s, respectively, which directly caused that the run up velocity of the last 10 m of Huang Geng lower than others thus hindering the improvement of his long jump performance.

The relationship between the take-off angle α of the body gravity center and the long jump performance L: It can be known from:

$$L2 = Vo^2 * \frac{\sin\alpha}{g}$$

L2 that the best projection angle is 45° under the circumstance that the projecting velocity will not change whereas it is impossible to adopt the angle of 45° in practice. With regard to the perspective of biomechanics, the root cause lies in that human body cannot take off at any angle and keep the height of jump unaltered. It is because energy loss is inevitable as the momentum of human body changes sharply in the quick take-off process that the larger the take-off angle is, the more energy will be lost and the lower will be the take-off speed, just as follow Table 5.

As the angle α is within certain limits, the long jump performance will be improved as the take-off

Table 4: One hundred meters, the run-up speed and the long jump performance

Athlete name	100 m performance (s)	The run-up speed (m/s)	The long jump performance (m)
Lewis	9.91	11.25	8.91
Beamon	10.3	10.70	8.90
Powell	9.95	10.86	8.95

Table 5: The relationship between the long jump performance and the take-off angle of Chen Zunrong

Performance (m)	Take-off angle (°)
7.94	18.9
8.01	19.9
8.17	22.8
8.26	23.66

angle α is enlarged. In accordance with the above list, if other conditions are not altered, the bigger the take-off angle is, the better will be the long jump performance of Chen Zunrong. However, α is not allowed to be too big or too small. If α is too big, the loss of the horizontal speed when taking off will be large and the jumping distance will be small; if α is too small, it is difficult to gain necessary jumping height and time thus affecting the result and unable to achieve ideal distance. Generally α is around 20°. The above list suggests that the take-off angle of Chen Zunrong is below 25° approximately. If other conditions are not altered, the bigger the take-off angle is, the better will be the long jump performance provided that α is within certain limits.

CONCLUSION

Through kinematical analysis of relevant parameters of each stage of athlete long jump from take off to landing, it is concluded that reasonable distribution of techniques in each period of time is the key to ensuring good competition results:

- The run-up speed is an important component of long jump and is a key factor determining the long jump distance. The athletes should increase the run-up speed as much as possible.
- We should enhance the ability to take off quickly, improve the take-off technique, increase the utilization rate of the run-up speed on the premise of develop the absolute speed vigorously so as to make adequate preparation for takeoff; we also ought to increase the proportion of vertical speed in the initial speed of take off so as to make better performance.

COUNTERMEASURES AND SUGGESTIONS

The limit for the utilization rate of the run-up speed of long jump is 100%, however, athletes cannot attain their own absolute speed in running up in order to complete the action of take off. The reason is that the ultimate goal of running up is to obtain the maximum controllable speed before taking off which can reveal the utilization rate of speed. It is thus clear that to increase the utilization rate of the run-up speed is a problem that cannot be ignored in training and teaching. Speed has become the core factor of long jump technologies. Therefore, it is necessary to put exerting the training of the maximum speed of oneself in the first place and provide conditions for increasing the run-up speed.

In the long jump training, we should attach importance to the practice of the run-up speed and its accuracy and spend most time on developing and improving the run-up techniques and the take-off techniques. Meanwhile, we should lay stress on coordinated development training of various factors, such as the run-up speed, the run-up ability, accuracy, the take-off techniques and special jumping ability, etc., so as to attain a relatively dynamic balance.

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