Simulation Study on the Sports Biomechanical Characteristics of Long Jumpers' Take-off Techniques

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Objectives: Based on the principles of sports biomechanics and long jump technical requirements, the technical factors affecting performance are discussed. Provide reference for the teaching, training and scientific research of the long jump project in China, improve and perfect the special sports technology and quality.Methods: In this study, the excellent men's long jump athletes at home and abroad in recent years are taken as research objects, and the sports biomechanical method is used on the basis of collecting and compiling large amounts of data in previous studies.Results:This paper makes a comparative analysis of the characteristics of run-up and Take-off Techniques of Chinese and foreign elite male long jumpers, in order to find out the advantages and disadvantages of Chinese athletes and provide reference data for the training of Chinese long jumpers.Conclusion: The research shows that the take-off technique is the key in the whole long jump. The take-off angle is an important factor that restricts the performance of long jumpers, and the stability of the brake point when the board is attached is more important.

Keywords:long jump exercise; take off technique; sports biomechanics
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The pros and cons of the long jump performance depends on the initial speed and the angle of the athlete's starting point. The initial speed and the rising angle of the center of gravity are determined by the horizontal speed obtained by the running and the vertical speed obtained during the jumping [1]. According to the research, the excellent athletes with a long jump performance of more than 6 meters have a running speed of more than 9 meters, and the initial speeds are all above 25 degrees, while the average athletes are much smaller. In the long jump competition in the world, the long jump movement is not limited to being sleek, stable and accurate. Only when the athletes master stable and difficult movements and superb jumping skills can they win in the competition [2]. Many countries have applied anatomy, physiology, biomechanics, psychology and other scientific theories to guide trainin g. It is worth mentioning that the United States has done a lot of research work in long jump training and scientific research, and has made remarkable achievements [3]. Its function is to change the direction of athletes' body center of gravity, create high initial speed of take-off, and make the body center of gravity fly to the air at a certain angle [4]. Data show that take-off makes the momentum of the total center of gravity of the human body change dramatically, thus obtaining take-off speed and take-off angle. A certain take-off speed and take-off angle basically determine the flying distance of long jump, and to a large extent determine the achievement of long jump [5].

In the related research of long jump at home and abroad, there are mainly technology, physical fitness, material selection and so on. In the analysis of long jump technology, the main method is kinematics analysis based on video analysis, and most of them are plane photography.

A few studies use three-dimensional photography to analyze the take-off stage of run-up [6]. Since the run-up and take-off stages are mainly horizontal and vertical movements, plane photography is suitable for this stage. The take-off stage is the technical basis and precondition for the take-off stage and subsequent entry [7-8]. The quality of take-off will affect the performance of the follow-up technical movements. To a certain extent, it has irreversibility to the follow-up actions (that is, the follow-up actions can not change the bad take-off effect), and more importantly, it will affect the athletes' competitive and psychological state. Therefore, the ability to fully convert the energy stored in the diving board into the energy of the athlete's off-board energy during the take-off process is the most critical part for the athlete [9]. This paper analyzes the two-dimensional and three-dimensional kinematics of the technical movements of long jump athletes in China. Through the calculation and analysis of the kinematics indicators of the key technologies in each action stage, based on the principles of sports biomechanics and long jump, the application of statistical tests, correlation analysis and other means It reveals some characteristics of the technical movements of Chinese long jump athletes and analyzes the technical factors affecting the performance [10].

Starting from the static force balance equation and the functional theorem of dynamics, the dynamic differential equations that the springboard should satisfy are established. The springboard is derived from the free vibration of the single-degree-of-freedom system of bending stress, deformation and vibration mechanics of material mechanics. The deflection curve equation, equivalent mass, natural frequency, vibration equation [11]. The high speed of running speed will make the jumping technique more difficult, affect the accuracy of the springboard, and the athletes will be unstable. It is very difficult to solve these problems, and some are even impossible [12]. This may also be the reason why foreign elite athletes have adopted the lower run-speed utilization rate almost without exception [13]. There are many studies to find out the factors that determine the performance of long jump, mainly in the following two categories. The first is mathematical modeling and computer simulation. This method is mainly to explain and predict the long jump. The second is to use kinematics and dynamics measurement methods to observe athletes. The advantage of this method is that it measures real long jump data, but it will be limited by the equipment and materials used in research and evaluation [14]. Through the analysis of the athletes' walking board movements, the required kinematics parameters are obtained, and the kinematics characteristics of the movement techniques are studied. In order to solve the organic combination of run-up and speed, two important problems should be solved. One is the runner's run-up speed. It requires a high body center of gravity, wide stride, elasticity, relaxation and coordination, and a good rhythm. The second is the combination of speed and takeoff [15].

In this paper, we propose a long jumper take-off technology simulation model based on sports biomechanics characteristics, which is an optimization model for long jumper take-off technology. In summary, our contributions are as follows:

This model is an optimization model of take-off technology of long jumpers based on the biomechanical characteristics of sports.

This paper presents a simulation model for the biomechanical characteristics of the long jump athlete's take-off technique.

The visualization effect of the model is better and the calculation result is more reliable.

In long jump, the basic elements of the technique are run-up and take-off technique, aerial posture and landing technique. Take-off technology is the most important part in long jump. The takeoff process is generally divided into three stages in time: the impact stage of takeoff footboard, the support leg landing stage, the buffer stage and the take-off and push-off stage [16]. Among them, the dividing line between buffer stage and pedal-stretch stage is the focus of dividing the whole takeoff movement structure. Later, foreign research divides pole vault into four stages. The first stage is run-up stage. The second stage is the pole insertion and take-off stage, from the moment when the jumping foot touches the ground to the moment when it leaves the ground, including the pole insertion. The third stage is the pole support stage, from the take-off foot to the maximum bend pole, straight pole and push pole [17].The fourth stage is the unsupported stage, from pushing to the pole, including the center of gravity to the maximum height. However, this division is still unable to evaluate the interaction between humans and jealousy during the pole-hopping process or to analyze its impact on performance. For the human body jumping movement, most of the domestic and foreign are focused on the study of the jumping problem under the inelastic support, and the experimental method is used to study the jumping problem, but these studies lack satisfactory explanation for the jumping movement. Seyfarth A uses the mass and rigid rod to simplify the human body and discusses the optimization of jumping motion. However, the ankle joint muscle moment is used as the control variable in this paper, which has no practical significance [18].

The impact phase is the end of the plate phase from the moment the foot is placed to the end of the support reaction force vertical force reaches the maximum [19]. At this stage, the time spent by the athletes is extremely short, but at this stage, the body and the ground give each other a huge impact, laying a good foundation for the athlete to obtain a reasonable vertical speed. In recent years, some studies of computational energy have divided the pole vault into two stages [20]. The first stage starts from the jump to the ground and reaches the maximum bend. At this stage, the athlete's kinetic energy is transformed and stored as the strain energy of the raft.The second stage is from the maximum bending rod to the center of gravity to the highest point. In this stage, the strain energy of the rod is transmitted to the athletes in the form of potential energy. This division involves a rigorous energy conversion process, but does not analyze the movement of the athletes before the pole insertion, that is, the run-up stage. For springboard diving, most of them use image analysis method to make some technical diagnosis and demonstration of movement technology, such as Nolan L's demonstration of the best pedal and extension position of springboard diving [21]. These articles have carried on the qualitative research and the discuss ion to the athlete in the springboard diving technology.

METHODS

Long jump takeoff is the turning point of long jumpers from horizontal to projectile, and the most complex technology in the whole long jump technology. Moreover, it is the most critical factor to determine the performance of the sport. Its task is to create as much vertical speed as possible under the condition of minimizing the loss of horizontal speed, so that the athletes can get a larger initial speed. Therefore, the research on takeoff technology has always been a hot issue for researchers. By consulting and analyzing the relevant literature at home and abroad, we can understand the current research status of swing leg in long jump takeoff. The video camera is used to scan and shoot the long jump finals on the spot, and the best test jump action film is selected for athletes, using the video analysis system of the Sports Science Research Institute of the State General Administration of Sports.Use two cameras to perform a fixed-point three-dimensional picture of the jumper's take-off to the over-the-go stage. Camera No. 1 is located on the right side of the runway. The shooting range is from the ground to the completion of the pole, the exposure time is 2/1000s, and the shooting frequency is 50 fields/s. Camera No. 2 is erected directly behind the crossbar. The shooting range is from the ground to the finish, the exposure time is 2/1000s, and the shooting frequency is 50 fields/s. The shooting range is from the footboard to the foot to the ground all the process map, and to ensure that the signal light is not blocked when it is illuminated, that is, the camera can capture the light up time screen. Using a force-measuring platform, the instrument is buried in the position of the springboard, and the force-measuring platform is used instead of the springboard.

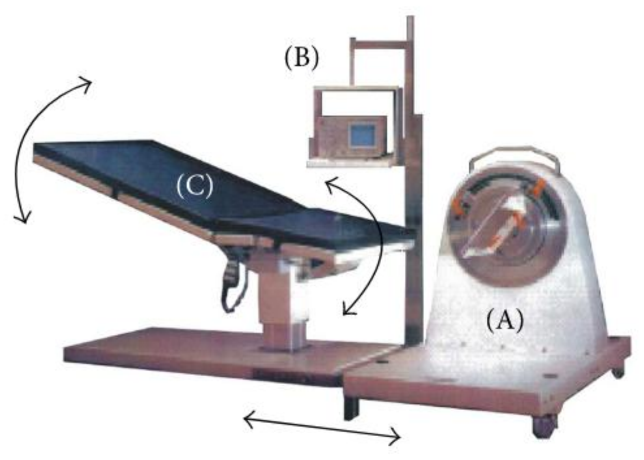
Kratole index refers to the weight per centimeter height expressed by the proportion of body weight and height, and the body circumference, width, thickness and tissue density reflected by relative weight or equal weight, that is to say, the index of human development evenness. Research data show that Clyto index is highly correlated with long jump performance. See Table 1 and Figure 1 below.

Table 1
Study object's Clayto index value

Athlete	Body weight(kg)	Height(cm)
P1	69	179
P2	67	163

A long-term MTS measurement of the ankle and ankle flexor was performed on the ankle flexor using an ankle dynamometer. This ankle dynamometer (Figure 1) consists of two main units: the power unit containing the actuator, power unit, angular displacement, angular velocity and torque sensors and their associated electronics.

Figure 1
Ankle Dynamometer System

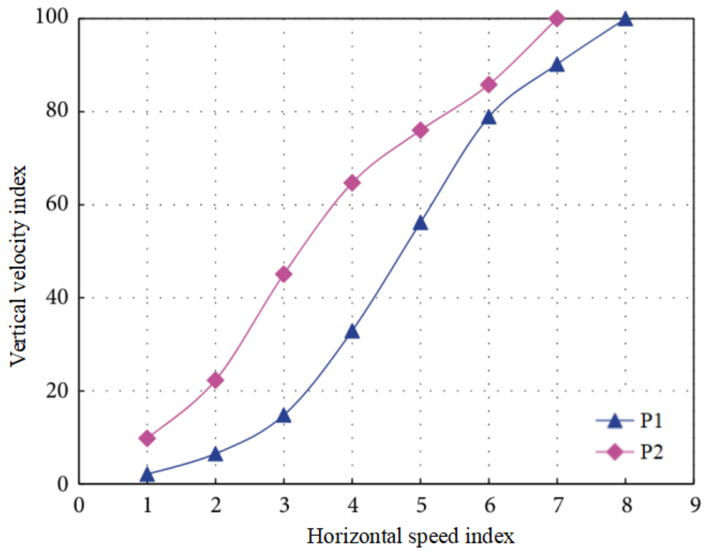


From Table 2 and Figure 2, it can be seen that the speed of the first-class athletes is 8.36m/s, the horizontal speed is 8.37m/s and the vertical speed is 8.71m/s. The horizontal speed and vertical speed of the other second-class athletes are 7.32m/s and 8.698m/s.

Table 2
Horizontal Speed and Vertical Velocity Value of the Center of Gravity of the Body When The Board is Placed

Athlete	Horizontal speed(m/s)	Vertical speed(m/s)
P1	8.36	8.37
P2	8.698	7.32

Figure 2
Horizontal Speed and Vertical Velocity Value of the Center of Gravity of the Body When the Board is Placed



Review the relevant literature at home and abroad according to the principles of run-up and take-off techniques, screen and determine the following main research indicators: speed related to running, pedal horizontal speed, vertical speed, uplifting horizontal speed, initial speed, speed utilization, speed loss , vertical speed and horizontal speed ratio, rising angle, and so on. The data of China's outstanding male long-distance athletes comes from the papers published by some scholars in academic journals and the research report of the National Sports General Administration's track and field research and technology services. During the take-off process, the swinging motion of the swinging leg plays an important role in reducing the braking at the ground, increasing the range of motion, and increasing the jumping speed. The swing amplitude is highly correlated with the lift angle. At the moment of take-off and take-off, the human body has forward rotational momentum. According to the reverse action of posture in sports physiology, the athletes must reflexively increase and accelerate the swing range and speed of the swing leg in order to achieve the dynamic balance of the body at the moment of take-off. At the same time, the distance between the center of gravity of the athlete's body and the maximum buffer of the knee joint is prolonged. Thus, the buffer time is increased, and the inactive swing action is also an important reason for the long buffer time. The whole process of swing movement is the process of maintaining body balance and gaining power. The athletes' mastery of this skill will directly affect the normal exertion of long jump technology, and there are differences in the take-up angle.

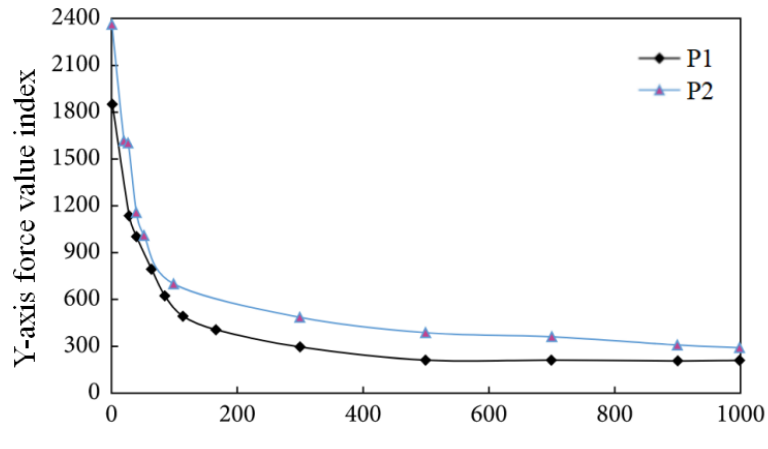
From Table 3 and Figure 3, it can be seen that the average vertical force of the subjects is

89.33N. The average vertical force of the first-class athletes is 96.33N, and that of the second-class athletes is 86.74N. It can be concluded that the maximum vertical axis force of the first-class athletes in the impact stage is significantly less than that of the second-class athletes, which may be due to the influence of the high vertical velocity of the second-class athletes when landing.

Table 3
X-axis and Y-axis Force Values When the Force is Maximally Applied to the Dynamometer

Athlete	X-axis force value(N)	Y-axis force value(N)
P1	89.33	86.74
P2	96.33	96.18

Figure 3
X-axis and Y-axis Force Values When the Force is Maximally Applied to the Dynamometer



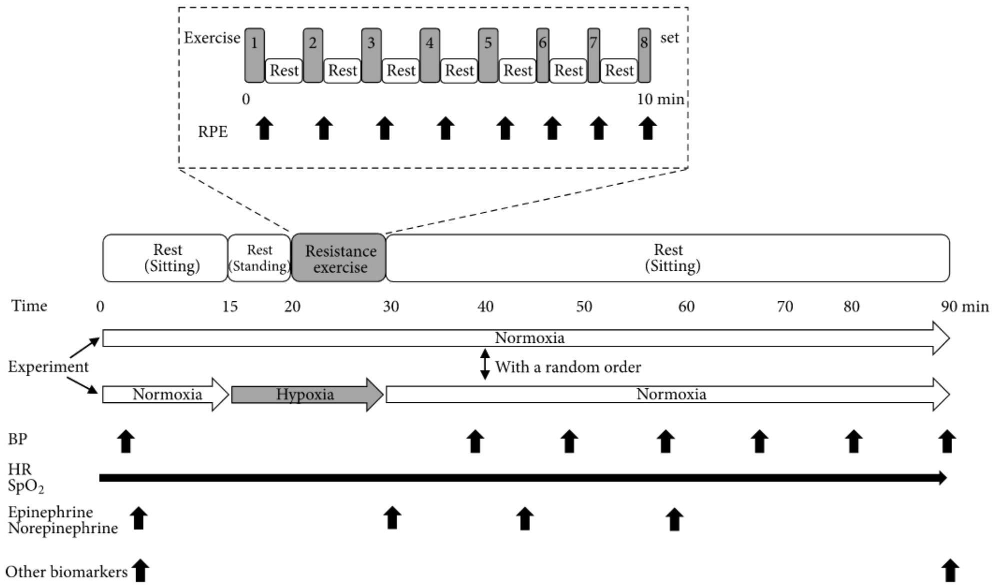
It can be seen from Table 4 that during the long jump start-up buffering process, the myoelectric integral value is extremely abnormal, and the muscle excitability law is significantly different from other people, especially the right rectus abdominis excitability is significantly stronger than others, and its value is 483. The mean value of myoelectric integral value of the right rectus abdominis of the remaining athletes was 27.

Table 4
EMG Integral Value of Each Muscle Measured in the Buffer Phase

Joint	Average value	Standard deviation
Right Pancreatic Intestinal Muscle	46.39	20.18
Right biceps femoris	36.78	19.68

In order to prevent the influence of blood pressure changes and minimize external stimuli, we controlled the room temperature at 25±1℃ ,during the whole research process. To further confir m that each participant repeated the 1-RM trajectory, we confirmed that all participants had the same 1-RM. No damage was found in the 1-RM test. The test was conducted a week before the main study. The ultimate acceptable maximum load lift is 1-RM. Figure 4 below is a schematic diagram of the experimental protocol for this study.

Figure 4
Schematic Diagram of Experimental Protocol for This Study



Run-up speed is the key of long jump technology and the main way to get kinetic energy. Effective run-up is the basis for reasonable completion of follow-up technical movements. Run-up speed determines whether athletes can cross a certain height, which is the necessary prerequisite for achieving excellent results. Therefore, the take-off process is the combination of human and board, and the coordination of human and board. In order to make the athletes coordinate with the springboard movement in the take-off process, the elastic potential energy stored in the springboard can be fully utilized. From the point of view of biomechanics, the mechanical characteristics, natural vibration frequency and the movement mode of the board system of springboard under external force are discussed, and the walking mode of the athletes is analyzed. The angular velocity of the swing leg increases from the landing of the takeoff leg to the maximum cushioning stage, and reaches the maximum when approaching the maximum cushioning of the takeoff leg. In this stage, the acceleration direction is upward and positive. Increased the tension of the working muscles of the take-off, creating good conditions for the muscle contraction during the stretching stage; entering the stretching stage after the maximum buffering, the angular velocity of the swinging leg is continuously decreasing, and the acceleration is negative in this stage, and Sudden braking from the swinging leg due to the moment from the ground. The kinematic indicators are divided into two parts, two-dimensional and three-dimensional. The two-dimensional kinematics indicators include the two-step step size in the run-up phase, the key technical indicators in the pace, the take-off phase, and the speed and height indicators related to the center of gravity of the feature. The three-dimensional kinematics index includes the joint angle and angular velocity of the main links of the upper and lower limbs from the maximum bending moment to the maximum height of the center of gravity.

RESULTS

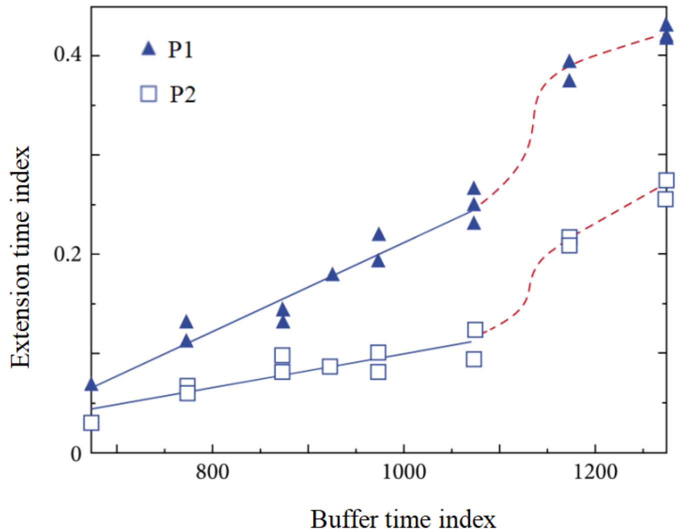
The initial speed and the rising angle of the center of gravity are combined with the horizontal speed that the athlete exerts in the running and the vertical speed obtained during the take-off. Compared with domestic elite athletes, the landing angle of the first-level athletes is basically the same as that of the domestic elite athletes, but the first-level athletes, including the domestic elite athletes, are significantly smaller than the world's best players. This shows that there is still a gap between the domestic athletes' grounding angle and the ideal middle ground angle. In the future training, especially in the training of grassroots athletes, the angle should be intentionally increased to make it close to the ideal value of 60 degrees. The most obvious kinematic feature of long jump exercise is the use of the kinetic energy obtained by the run-up, which maximizes the direction and speed of movement of the person's center of gravity.Therefore, from the perspective of technical principles, the core of long jump technology is how to use run-up speed to create a reasonable take-off angle of the maximum take-off speed. At the same time, this technology is also conducive to take-off foot to actively and quickly pedal. Positive and sufficient forward motion of hip joint drives the center of gravity of the body to move quickly across the vertical plane of the support point, and then forms a smaller ground angle. The body has a better forward, which makes the horizontal speed faster. Then the take-off pedal movement will be more closely connected, creating favorable conditions for the fast, active and powerful pedal.

From Table 5 and Figure 5, we can see that compared with the world's elite athletes, the take-off time of the research subjects is obviously longer than that of the world's elite athletes in comparison with the domestic elite athletes. The take-off time of the domestic elite athletes is also significantly longer than that of the world's elite athletes. The take-off time of the domestic elite athletes is basically the same and there is no difference.

Table 5
The Time Value of the Excellent Athletes to Complete the Buffering and Stretching Stages

Athlete	Buffer time(s)	Stretch time(s)
P1	0.063	0.076
P2	0.055	0.461

Figure 5
The Time Value of the Excellent Athletes to Complete the Buffering and Stretching Stages



From the point of view of mechanics and dynamics, we will establish the dynamic equations that the springboard should satisfy. First, the balance between force and moment has the following equation:

$$Y_j(t)=\phi\left(\sum_{i=1}^{n} w_{ji}x_i-\theta_j\right) \quad (1)$$

The force arm of a certain point remains unchanged. We take the f point as the reference point, and assume that the moment o f the springboard at any time from the f point x is o, then there are:

$$\mathrm{o}_{\mathrm{j}}(t)=f\left(\left[\sum_{i=1}^{n} w_{ij}x_i\left(t-\tau_{ij}\right)\right]-T_{ij}\right) \quad (2)$$

The x board represents the deflection of the springboard from the fixed end at any time. F is the moment of inertia, n is the width of the springboard, and t is the thickness of the springboard. By calculating the integral of formula (2), the following results can be obtained:

$$F(x)=\frac{1}{1+e^{-ax}} \quad (3)$$

Because the o point on the springboard is always fixed and the x point is fixed after it is determined, the deflection is 1 at any time, that is, the displacement is always 0. According to the above formula, it is available:

$$G_g(s)=\frac{K_g}{1+T_{d0}s} \quad (4)$$

After the human body falls from the height s and collides with the beam, the maximum impact load subjected to the maximum deflection at the free end of the beam is K. At this time, the bending moment equation of the beam is given by equation (4):

$$G_a(s)=\frac{K_a}{1+T_a s} \quad (5)$$

Let the maximum deflection of the free end after collision be G. According to the above formula, it can be obtained that:

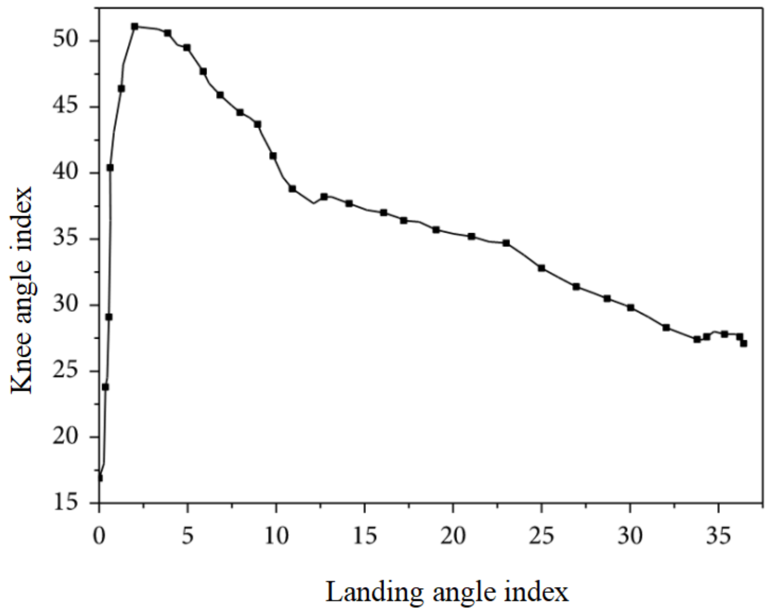
$$G_r(s)=\frac{K_r}{1+T_r s} \quad (6)$$

It can be seen that the deflection of impact load is much more than twice the static deflection. The higher the height before impact, the greater the deflection of impact load. The maximum impact force obtained from formula (6) is:

$$Q(u_{ij})=\sum_{i=1}^{n}\underset{1\le j\le m}{Max}\{g_{ij}(T)\} \quad (7)$$

According to the information, athletes do not have a larger angle or a smaller angle when they jump on the ground. They have a certain angle. Only a reasonable landing angle can have a high-quality take-off to achieve excellent results. Figure 6 below is a graph showing the instantaneous landing angle of the jumping leg and the angle change of the knee joint.

Figure 6
The Curve of the Instantaneous Landing Angle and Knee Angle Change Value of the Jumping Leg Landing



In order to minimize the loss of horizontal speed, firstly, the braking resistance generated by the pedal should be minimized; this requires the athlete to run the last step of the step, the step frequency should be large, and the jumper should be on the upper board. Use the full foot pedal near the front of the center of gravity projection point to increase the ground angle. It can be seen that the knee joint of the second-level athletes is obviously more curved than the first-class athletes, while the first-level athletes even include the domestic elite athletes whose knee joints are more curved than the world's top athletes, which indicates that the lower limb strength of Chinese athletes is significantly lower. In the world's top athletes, the ability to retreat and contraction is obviously weak. Therefore, the knee joint will seriously affect the quality of the completion of the jump during the impact phase. The lack of strength of the lower limbs is also a major obstacle for Chinese athletes to catch up with the world. Chinese athletes, especially grass-roots athletes, should pay attention to the training of lower limb strength, especially for the long jump technical characteristics of strength training. After buffering the upper board, the athletes with good results can reduce the swing radius and inertia of the swing leg by bending the knee joints obviously. This technique swings the leg around the hip in a timely manner, and the swing angular speed is much higher, the body center of gravity upward displacement is very obvious in the support buffer phase.

Assuming that the deflection curve of the moving beam is the same as that of the static deflection curve of the free end, there are:

$$y_{f-n_m} = \sum_{i=1,i\neq n}^{N} \sum_{l=1}^{M} \sqrt{p_{i_l}}\, \boldsymbol{h}_{i,n_m}^{T} \boldsymbol{W}_{i,i_l} s_{i_l} \quad (8)$$

Since the plate has no deflection change at the fixed end and the free end when the person is falling, the speed is zero, so that the M plate is at any point x along the elastic curve, the M plate can be written as an N plate. The maximum kinetic energy of the board itself is:

$$P_{f-n_m} = \sum_{i=1,i\neq n}^{N} \sum_{l=1}^{M} p_{i_l} \left\| \boldsymbol{h}_{i,n_m}^T \boldsymbol{W}_{i,i_l} \right\|_2^2 \quad (9)$$

After the athlete touches the board, the potential energy added by the board is stored by elastic deformation: it can be obtained by the formula, so that the two maximum values are equal to the natural frequency of the board:

$$R_{n_i}^C = \log_2(1 + \frac{p_{mac,n_i} \left\| \boldsymbol{h}_{mac,n_i}^T \boldsymbol{W}_{mac,n_i} \right\|_2^2}{\sigma^2}) \quad (10)$$

It can be seen that the greater the stiffness of the plate, the higher the natural frequency. The larger the mass of the plate, the lower the natural frequency. The maximum kinetic energy of the whole system is:

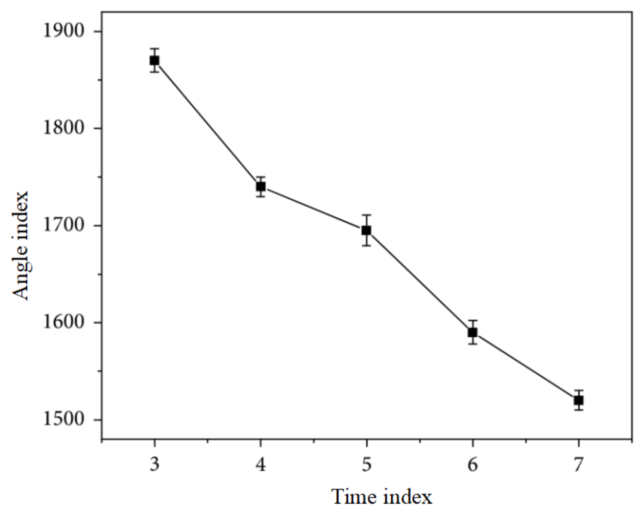
$$G^m = \left[G_1^T, G_2^T, \ldots, G_k^T \right]^T \quad (11)$$

So the natural frequencies of human-board coupling are:

$$A^T G = \sum_i A_i^T G_i \quad (12)$$

It can be seen from Figure 7 that the angle of the jumping leg ankle joint is not a gradual decrease in the buffering stage until the buffer is maximum, but a tendency to change first and then decrease. At the moment of take-off, due to the inertia of the running speed and the gravity of the body, the pressure on the jumping leg is enormous, forcing the kicking knee joint and the ankle joint to flexibly flex the cushion to reduce the impact force on the ground due to inertia.

Figure 7
Curve of the Angle of the Leg Joint of the Take-Off Leg With Time During the Take-Off



To increase the vertical speed, it is an ideal time to take off when the line between the center of gravity and the support point is 90 degrees from the ground. This is not only the loss of speed, but also the best position for obtaining vertical speed. At this time, the stretcher pulls hard, and the reaction force is vertically upward through the center of gravity of the body, and does not generate force decomposition, so the take-off effect is best. Send out before, help the waist to turn, so that the swinging leg moves forward quickly. In fact, the speed of each point on the beam changes sharply, and the acceleration change is also very obvious. Under the action of dynamic load, the dynamic stress and dynamic deformation generated in the beam are larger than those under static load due to the inertial force caused by the acceleration. Much more. Therefore, the influence of acceleration on the strength, stiffness and stability of beams must be considered in the dynamic load problem. If the angle between the two legs is large when landing on the board, it shows that the technology is not compatible with the speed and take-off ability, the result will not only increase the loss of horizontal speed, but also increase the impact load of the take-off leg when landing on the board, which is not conducive to the exertion and utilization of leg explosive force and affects the cushioning effect. At this time, as long as the stress does not exceed the proportional limit. Because the force is mutual, this will lead to pedal to give athletes, especially the second-class athletes a greater force, and this force is not conducive to take-off, indicating that knee joint, medullary joint and stepping joint are insufficient to buffer the instant force of take-off, which may be caused by the lack of lower limb strength or non-standard take-off technology, which needs to be further improved.

DISCUSSION

Before the jump step, because of the press and push-out of the third right foot, the elite athletes obviously have a descending range of the board, and then the springboard forms an obvious 1.8 vibration period. At the same time, the real coupling of the human board should be that the mass of the human body and the mass of the board become a whole to move. At this time, the frequency of the human board coupling should be the same as the center of gravity of the human body and the velocity of the plate moving on the end of the board in the vertical direction. The performance of long jump depends on minimizing the loss of horizontal speed and maximizing the vertical speed when taking off. In addition, run-up should have relaxed high stride frequency, minimum energy consumption stride length, and appropriate acceleration rhythm, uniformly accelerating to the maximum speed. At the same time, the run-up to the last second step increases, the last step is shorter than the second step, the step frequency is faster, the take-off leg is straight, the whole sole landing is lighter, and the landing angle is larger. The torso of our high jump athletes began to whirl from the moment of maximum bend, and the speed of the right jumper reached the maximum. The active push-pull support of the left upper limb and the positive pull of the right elbow were the key to the rotation. Moreover, the high-handed athletes of China's high jumpers failed to raise the height of their center of gravity. When the right hand pushed the hips, the height of the center of gravity decreased prematurely. For high-level long jumpers, it is best to use the "walking" long jump technology, which can coordinate the completion of the combination of running and jumping, and create good conditions for improving long jump performance.

Human Subjects Approval Statement

This paper did not include human subjects.

Conflict of Interest Disclosure Statement

None declared.

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