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Kinetics model analysis and technical optimization study on the elite men's triple jump

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ABSTRACT

For the existing action defect problem of Chinese Triple jump athletes, this paper studies the motion parameters and technical actions of triple jump athletes through the analysis of kinematics, combines the whole process of triple jump, uses the mathematical statistical methods, by comparing Chinese elite athletes with foreign elite athletes, and concludes that Chinese athletes' speed and take-off angle is too small, they have deficiency in the integrity and continuity of the action. Therefore, in the future training we should pay attention to strengthening the training of speed, increasing the ground pedaling angle when taking off, adjusting the power ratio of triple jump, focusing on strength training of upper body; it studies the taking-off angle of the third jump to find the best jumping angle. Through the study of the triple jump technique, this paper raises rationalization proposals for the improvement of technological level, which is aiming at improvement the technological level of China triple jump.

KEYWORDS

Kinematic model;
Mathematical statistics;
Jumping angle;
Triple jump.

INTRODUCTION

In 1986, the triple jump officially emergences as an Olympic sport, which is added late into field events in all Olympic projects. The development level of China's triple jump is rapid, Chinese player Zou Zhenxian once jumped a good result of 17.51m in 1981, which makes China's track and field record keep for 26 years. However, the current world record is 18.29m jumped by Britain Edwards. The average distance jumped by Chinese elite athletes is only 17.50m around, and there is still a large gap between the world first levels. We also need to explore technical skills of triple jump deeply, find a more efficient way, and come up with better improvement suggestions for the Chinese athletes.

Triple jump venue is consists of five parts: the runway, the take-off board, the take-off display board, plasticized display boards and the landing area. The distance between the take-off board and the landing area of men's venues is 13m, and the distance of woman venue is 11m. In the triple jump competition, it gets its name because the players need to do three different jumps in the run-up in a row. The first hop is jumping on one foot, landing on the floor with the take-off leg; the second jump is stride jump, landing on the floor with a

swinging leg; the third jump is jump falling into the bunker with both feet. Triple jump can be roughly divided into four stages: the run-up, jump on one foot, stride jump and jump. In the triple jump competition, rapid run-up, fast-paced triple jump, full utilization and play of horizontal velocity, reducing the loss of horizontal velocity, these are the current main technical points. The triple jump run-up, one foot jump and stride jump is the acceleration and continuity of the speed. Good or bad of the completion directly affects the play of the third jump, and the third jump directly bears on the final result of the triple jump. Thus we study the run-up, one foot jump and stride jump as a whole, and focus on studying the third jump, as well as proposes skills to improve the performance of athletes and helps athletes to help achieve better results. Now however most of Chinese literature studies in the triple jump are on run-up, and the study on the upper and lower body movements for the entire process and the final jump is relatively small. It makes reference literature for triple jump athlete limited.

In this paper, by the kinematics knowledge, it considers from the continuity of action, links the entire process, by analyzing the kinematic parameters of athletes during the entire process of the jump and comparing with international athletes, sums the insufficient of Chinese athletes and suggests corresponding improvements, completes the technological improvements.

DYNAMICS AND TECHNICAL OPTIMIZATION MODEL

Basic theory and problem analysis

Kinematic analysis of athletes in the triple jump is similar to the parabolic movement. Suppose in each stage the take-off speed of the athletes is v_0, the jumping angle is α, the jumping distance of each segment is S, by ignoring air resistance the gravitational acceleration is g, the numerical component of the speed is v_y, the horizontal component is v_y, by the kinematic equations we can obtain that:

$$v_x = v_0 \cos\alpha \quad (1)$$

$$v_y = v_0 \sin\alpha \quad (2)$$

$$S = \frac{v_0 \cos 2\alpha}{2g} \quad (3)$$

From the above equation (3), the faster the speed of the gravity center of human is, the bigger the taking-off angle is, the higher the center of gravity is, the better the result of the triple jump becomes. To improve the starting speed, it is necessary to increase the athletes' approach speed, try to avoid reducing the acceleration in the jumping process, and maintain the upgrade rate of the speed. Approach speed determines the take-off speed of triple jump, which is very important in the triple jump. Three jumps of the triple jump are closely related; the appropriate proportion of triple jump can make the athletes' strength and speed play better. The third jumps are mutually influenced and restrained, also closely linked. As for the Chinese athletes, the ability of the third jump is generally low.

Research on the approach speed

Approach is to increase the speed, the greater the speed is the greater the take-off speed becomes. But the speed of Chinese athletes in the run-up phase is generally first quick back slow down. Penultimate step's speed decreases, resulting in reduced take-off speed. The speed of the world's top athletes in the last two steps, either increases, or remains. The take-off speed is relatively large, and the results will be better.

Below it takes the elite triple jump athletes in the world and China as the research object, takes the kinetic parameters of the triple jump run-up as the data source for analysis, the specific is as in TABLE 1 below.

The data in TABLE 1 shows that the velocity of the world's elite athletes in the run-up phase is small, the speed of the penultimate step decreases, and the speed of the final step increases. The Chinese athletes' velocity at run-up phase is relatively large, the speed of the penultimate paragraph increases, the speed of the final step decreases. And just it is opposite to that of the world elite athletes. As can be observed by the data in TABLE 1, the pop-distance athletes is directly proportional to the speed of the last step. The main problems of Chinese athletes in the triple jump movement are the low on board speed, the speed of the penultimate step before the taking-off is too great. The reason is that Chinese athletes will adjust posture in the last step, which

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TABLE 1 : The kinematic parameters when jumpers approach

Name of Athlete	Performance (m)	The horizontal velocity of the run-up phase (m/s)		Horizontal velocity of the center of gravity (m/s)		Horizontal velocity of the final step and the maximum speed of the penultimate step (m/s)
		11-6m	6-1m	Penultimate step	The final step	
Kasarda	17.85	10.14	10.22	10.10	10.30	1.008
Ur lupu	17.64	10.19	10.36	10.10	10.60	1.023
Pierre de	17.22	10.13	10.16	10.10	10.50	1.033
Zou Zhenxian	17.34	10.58	10.47	10.70	10.50	0.939
Zou Sixin	17.31	10.42	10.43	10.80	10.30	0.972
Chen Yanping	17.22	10.40	10.31	10.60	10.30	0.972

causes the speed on board reduces, and the jump speed decreases. Meanwhile it will also result in wasted power.

It is recommended that athletes increase the on board speed, and focus on increasing the absolute velocity. In the run-up process athletes should consider raise the power to the maximum, and cannot affect the power play at the same time.

Changes of the horizontal speed and vertical speed in triple jump

Research on changes of horizontal velocity

Through the analysis of kinematic knowledge, it not difficult to find that the action technique of triple jump landing and the take-off stage; the main observations include horizontal speed and vertical speed, and the change of horizontal speed is the key point. In recent years, on issues of velocity changes at triple jump ground landing and jumping phase, especially on the "how to reduce the loss of horizontal velocity" and "improve utilization rate of the horizontal velocity", experts at home and abroad have done a lot of research work.

On the basic law issue in the horizontal velocity variation during the triple jump, scholars from different countries also gives the study, as shown in TABLE 2. As can be seen from the data in TABLE 2 the stepping of each jump has lost a certain horizontal speed, the reduced scope of the horizontal velocity for one foot hop, stride jump and jump is respectively 5%~9%, 7%~15% and 13%~20%.

TABLE 2 : The average speed when stepping and jumping units: m/s

Name	The final step of approach	Jump on one foot	Stride jump	Jump
Bober	—	8.2	7.2	7.0
Miller	10.02±0.68	9.42±0.33	8.06±0.39	6.96±0.34
Hay	10.26±0.21	9.59±0.36	8.44±0.42	6.93±0.29
Zissu	8.82	8.34	7.45	6.20

As can be seen through TABLE 2, the horizontal speed of triple jumpers will be reduced in the ground landing and buffer two stages. So we should compensate for the horizontal speed by increasing the kicking action, and try to reduce the decrease of the horizontal speed. The maximum horizontal velocities of the tested athletes on the board, at the end of the buffer and when jumping are respectively 10.16m/s, 8.88m/S and 6.59m/S; The minimum speed is 7.99m / s, 6.47m/s and 6.25 m/s, the horizontal velocity has varying degrees of damage. As can be seen by the data, the horizontal velocity of triple jump athletes in the game is not straightly decreasing, but " first fall-then rise-and fall, " Of course, the overall trend in the horizontal velocity does not increase, but decreases. China scholar found that from the study (2003), the loss rate of the triple jump horizontal speed for World Elite Male Triple Jumpers are respectively 6.57%, 10.5% and 19.45%, the total loss rate of the triple jump is 36.52% (TABLE 3).

In the study of the reasons for the triple jump athlete's horizontal velocity loss we know: "Excellent performance of triple jump depends not only on the absolute speed, also depends on the effectiveness of the speed utilization"; and the studies of American scholars Clifford • La Kaisi (2001) further proved: "the beginner's horizontal velocity from the one foot jump

TABLE 3 : The average value and loss rate of the horizontal velocity unit: m/s

Project	Horizontal velocity on board	Horizontal velocity at the end of the buffer	Horizontal jumping velocity	Loss rate of the horizontal velocity
Elite Athlete	10.05±0.14	8.31±0.58	9.09±0.38	8.8%
Ordinary athlete	8.36±0.38	7.06±0.35	7.00±0.77	16.1%
Novice	8.76	7.21	6.96	20.0%

to stride jump decreased by 4.9%; while the speed of elite athletes often dropped as much as 13%; the loss of horizontal speed from the stride jump to the third jump level is similar to athletes with different skill levels, it is respectively 13.6% for the beginner and 13% for elite athletes". It can be seen from the data in TABLE 3, novice proceeded conscious restraint in the first jump in order to reduce the loss of physical agility.

Through the study of China's outstanding triple jump athletes, the of, the main reasons of speed decline and loss from the run-up to the take-off stage include: the horizontal velocity for the first two steps of the triple jump athlete's centroid before jumping decreases, which has a direct relationship with the athletes intentional attention of the jump action, results in large gap between two-step length before the take-off, and no doubt increases the difficulty and accuracy of jump. Dating back to the men's triple jump final in 1995 World Championships, Lu Gang, Wang Zongping (2003) and others conducted analysis on eight players of them and found: in terms of the loss rate of horizontal velocity for each jump and the stepping jump, Conley is minimal, that is his merit is the most prominent. However, compared with Edwards, Conley's performance at 16.69m has been lagged far behind. This fully shows that the loss rate level of the horizontal velocity is just one antecedent that determines the final score of the triple jump. This single technical parameter cannot be the sole criterion to predict the performance, that is, although it is very critical to raise the horizontal speed of athletes, but it is not the only way.

Study on changes of the vertical velocity in triple jump

About the basic law of vertical velocity in triple jump, scholars at home and abroad believe that the vertical velocity almost increases with the constant proportion in the supporting stage of each jump; it reaches the peak before jumping and then begins to decline. In addition, Song Yawei and Ma Jizheng (2002) found from the study that "changes of the vertical velocity in the three jumps are gradually increasing, which is related to the size of impact force when landing of the second jump and the third jump. Especially in the third jump, although the athletes lose a large horizontal velocity, but obtain a larger vertical speed." Typically, vertical velocity at the take-off phase in stride jump is smaller than that of the other two phases, vertical velocity at the take-off phase of the third jump is maximum (TABLE 4). It is mainly due to the vertical generated reaction force after athletes' one foot jump increases with the increase of one foot jump length; studies have shown that: the generated maximum vertical force is about 14-22 times of one own weight for male athletes whose one foot jump length is about 5-5.3m. Therefore, from a logical reasoning, if the triple jump athletes can produce larger vertical stepping and jumping velocity in stride jump, then its stride jump distance will be more than the distance of the one foot jump and the third jump. In the actual pro-

TABLE 4 : The average vertical speed when ground landing and stepping and jumping unit: m/s

Name	Jump on one foot		Stride jump		Jump	
	Ground landing	Stepping and jumping	Ground landing	Stepping and jumping	Ground landing	Stepping and jumping
Bober	—	2.65	—	2.06	—	2.57
Miller	0.31	0.20	0.19	0.27	0.27	0.30
Hay	—	2.2±0.04	—	1.9±0.27	—	2.6±0.20
Zissu	—	2.03±0.29	—	1.55±0.46	—	2.55±0.58

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cess of stride jump, athletes can not produce the desired vertical speed, resulting in decline of the vertical speed, which also shows the difficulties of improving the vertical speed of the stride jump.

Maximizing the contradiction between the horizontal speed and vertical speed to make the problem of "How to improve the vertical speed without affecting the play of horizontal speed" receive widespread concern. Former Soviet feat coach BANoanb (1985) once suggested: "when landing the vertical velocity of athletes' centroid is zero or a small positive value; if it is not subsequently reduced, then the entire reaction impulse of the ground increases the upward vertical velocity, and ultimately helps to increase the vertical jumping speed". In addition, the analysis of Liu Shifan and Song Ying-hua (1992) (TABLE 5) also proves: " the jumping vertical speed showed a significant negative correlation with the downward landing vertical velocity ($R = - 0.689$; $P < 0.01$). The smaller the downward vertical velocity when landing is, the greater the vertical jumping velocity becomes. Although reducing downward vertical speed will reduce the vertical impact impulse when touching the panel, but alleviating the burden of the taking-off leg is in favor of the rapid kicking of the taking-off leg, and the vertical impulse will not decrease". This means that athletes should be "running" through the pedal at the jumping moment instead of consciously "stamping" on the board. The study of Lu Gang, Wang Zongping (2004) shows that "if the landing angle is too small, it increases the forward speed and magnitude of the center of gravity to reduce the loss of horizontal speed when taking-off. Therefore when the take-off time is certain, it will inevitably increase the forward movement in the horizontal direction during take-off and impacts the movement of body centroid in the vertical direction, and it is negative to get vertical speed." The related data is shown in TABLE 5.

TABLE 5 : The average vertical jumping speed units: m/s

	On board	End of the buffer	Jumping
Elite athlete	-0.672±0.497	1.739±0.321	2.937±0.398
Ordinary athlete	-0.406±0.365	1.975±0.2096	3.382±0.338
Novice	-0.989	1.511	2.413

The angle changes of the landing and take-off phase during triple jump process

The study on the landing angle and ground stomping angle

The ground landing angle and stomping angle can be understood as the angle between the connection of hip, knee and ankle joints with the horizontal plane when the taking-off leg touch the ground and kick off the ground, and the sizes have great impact on sports performance. Lu Gang, Wang Zongping (2004) found in the study: "The smaller the landing angle is, the greater the front supporting resistance becomes, the larger the braking action when landing is, the larger the loss of horizontal velocity becomes, and this loss is due to the impact of the take-off leg with the ground at the landing instant, which will not translate into vertical velocity and is totally lost." Therefore, in the ideal case, the athlete should use the small degree to jump and use the wide angle to land, but it is impossible. Kreer and Poqov (1986) found that the landing angle of stepping and jumping is substantially equal, especially in single foot hop and stride jump phase. The main reason is: theoretically, kicking at the top of the supporting point is most ideal, without losing horizontal velocity, beneficial to the gain of the vertical take-off speed. However, this will cause the pedal too late and muscle elasticity tension decrease, which is difficult to play a greater kicking power in a very short period of time, and thus the vertical velocity also decreases the amplification. So, the former Soviet training expert Cub (1991) thinks: "Kicking from 3 ° to 8 ° of the supporting point, helps improve the kicking strength, so that the reaction force can get through the body more easily."

Another study shows that, the step jump that has a relatively smaller landing angle has a relatively large takeoff angle; conversely, the one with significantly larger landing angle has a relatively small takeoff angle is. Under the premise of assuring strength quality, the ground landing angle is small, we can muscles enter the tense shrink earlier. The rapid contraction before the body weight across the supporting point, can get a good takeoff effect, but also increase the take-off angle, improve the distance from the body center to the board, and helps to improve the performance.

The study of Li Hung Kong et al shows the two

angle changes of elite athletes' triple jump, the landing angles are respectively 69 ± 3 °, 68 ± 2 ° "and 66 ± 20 °, the takeoff angles are respectively 62 ± 2 °, 60 ± 2 ° and 63 ± 3 °. The average landing angles of Chinese athletes are respectively 65.13 ± 1.57 °, 64.6 ± 2.12 ° and 62.28 ± 0.99 °, the take-off angles are respectively 66 ± 1.91 °, 55.16 ± 1.21 °, and 58.27 ± 1.14 °. It explains that Chinese athletes need to improve their control ability of the landing and taking-off angle. TABLE 6 shows the stepping and jumping angle of different levels of athletes.

Proportion problem of triple jump

Technology classification of triple jump and ratio division of triple jump

There is a variety of partitioning method on the technological types of triple jump. Currently both inside and outside scholars use the types classification standard put forward by American scholar James • Sea (1992), namely: one foot jump type –the percentage of on one foot jump at least is 2 % greater than the percentage of jump, jump type – the percentage of jump is at least 2% greater than the percentage of one foot jump and balanced type –the percentage difference of one foot jump and jump is less than the standard of division. If we take 5% as the standard, then all of them belong to the athletes with "balanced" technology, if we take 4% as the standard, then 75% of them belong to the athletes with "balanced" technology, and so on. But the value is too low, which cannot distinguish the real difference between athletes, so the standard based on 2% is appropriate, this can effectively distinguish the difference between the different technical styles. According to this standard, some of the world famous triple jumpers' technology has been divided in the following TABLE 7.

Since the 1990s, the "Speed Style" with characteristics of the fast run-up speed, large motion range, a short supporting time, the increasing proportion of third jump is a popular new technology. Edwards is a typical representative of this technology, and Chinese player Chen Yanping also belongs to this technical style. In addition, a number of different classification methods on the Triple Jump technique types also appeared in some other domestic and oversea information, for instance, it is divided into "high-jump type" technology and "flat-jump type" technology according to the different trajectory heights of athlete's centroid during the triple jump. Depending on the athlete's fitness and training modes, it can be divided into "force type" technology and "speed type" technology; in addition, according to the different technological characteristics of athletes' actions in the triple jump process, it can be divided into "combat style" technology and "buffer type" technologies.

Research on the relationship between the best triple jump proportion and triple jump performance

In triple jump, the standards that can reflect the hori-

TABLE 6 : The average value of each stepping and jumping angle units: m/s

	landing angle	Take-off angle	Take off amplitude	Maximum buffer knee angle	Jumping angle
Elite Athlete	64.28±0.49	68.5±1.02	47.04±1.12	134.25±2.69	17.98±1.69
Ordinary athlete	61.01±2.99	74.4±2.94	44.43±2.94	135.87±4.15	25.76±3.14
Novice	59.7	73.4	46.9	132.3	20.5

TABLE 7 : Technological type statistics of world elite male triple jumpers

Name	The proportion of jumping on one foot %	Stride jump proportion %	Jump proportion %	Achievement (m)	Years	Technology type	Remark
Schmidt	35.2	29.5	35.3	17.03	1960	Balanced type	Break the world record
Banks	35.2	27.6	37.2	17.97	1985	Jump type	Break the world record
Edwards	33.1	28.5	38.4	18.28	1995	Jump type	Break the world record
Conley	32.0	30.0	38.0	18.17	1992	Jump type	Olympic champion
Saneyev	37.0	29.0	34.0	17.39	1968	Jump on one foot type	Break the world record

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zontal velocity distribution of athletes and the force degree of triple jump athlete include the distance between each jump. This factor is also the important reference for coaches and athletes to determine training methods and technical indicators. The distance of each jump has a direct impact on the results. Different proportions of triple jump will form into different technology types and characteristics. From the development trend of current triple jump technology, to shorten the first jump and increase the third jump is a big current trend.

Yang Cunbin (1995) from the Beijing Normal University took the 30 groups of test scores of the current world-class players in the triple jump as the basis, used the regression model of quadratic response surface, studies the relationship between the total score of three jump and triple jump length, and found that: the best proportion of the one foot jump in triple jump is 35.14%, that of the stride jump is 27.55%, and that of the jump is 37.28%. Cui Yunlong collected the triple jump proportion and performance of 18 World Elite Male triple jumpers from 1931-1981; Through statistical analysis, the proportion of the first jump has a development trend from the high phase to the low phase, the proportion change of the second jump and third jump is not significant, the suitable proportion of triple jump is 35.93%, 29.49% and 34.58%, meanwhile the best results of the triple jump can reach 18.48m. Through years of analysis and research, Professor Jin Zongjiang made provisions on the proportion of the best triple jump: "the proportion of best triple jump is the triple jump proportion that is adapt to the individual characteristics such as the athletes' structure and motion quality, technical style and body shape, that can utter mostly transform the athletes' movement quality into athletic performance. The specific data is shown in TABLE 8.

TABLE 8 : The best triple jump ratio of men's triple jump that national scholars believe

Author	Percentage %		
	Jump on one foot	Stride jump	Jump
Webster	37.5	25.0	37.5
Oda	35.3	29.4	35.3
Tan	37.2	29.5	33.3
Nett	36.0~37.0	29.0~30.0	33.0~34.0
Kreer 和 Poov	37.5~38.0	29.0~29.5	32.5~33.0

Based on the above analysis, the existence interval of the triple jump ratio for triple jump athlete varies according to the different levels; therefore in training, competitions and other practice, we should determine the interval range of the triple jump's ratio based on the level of the athletes, thereby develop a corresponding jumping program; The mode of singly adopting a fixed ratio for an object is not desirable.

Calculation on the optimal jumping angle of the third jump

By analysis of the video, the last hop of the triple jump can be decomposed as in Figure 1.

Figure 1 shows that athlete belongs to the flight phase after jumping, only receives the effect of gravity and air resistance, since the horizontal speed v_x is larger the drag area is larger, the vertical speed v_y is smaller, the drag area is smaller, therefore the resistance in the horizontal direction is constant f and the resistance in the vertical direction is negligible. The distance of athletes' third jump is crucial, how to make the distance of the third jump farther is an important means to improve the overall performance. According to Figure 1 and kinematics, the take-off speed v of the third jump and

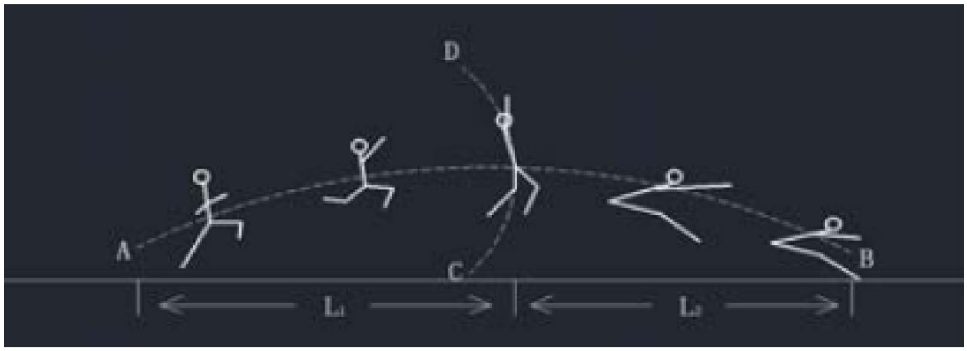

Figure 1 : Decomposition of the jumping movements

the angle α is the key factors to affect the jump distance, this paper finds the best take-off angle α by combining with the kinematic equations, and the specific calculation steps are as follows. The take-off angle refers to the angle between the instantaneous velocity direction when athletes jump and the horizontal direction, and the equation can be obtained:

$$\tan\alpha = \frac{v_y}{v_x} \quad (4)$$

Based on kinematic if you want to jump the farthest, you should use up all speed potential at the landing time, so that the speed reaches 0, the formula can be derived:

$$v_x = at_2 \quad (5)$$

$$a = \frac{f}{m} \quad (6)$$

Where in f is the air resistance, from (5) (6) we know that:

$$v_x = \frac{ft_2}{m} \quad (7)$$

Analyze the vertical velocity v_y:

$$v_y = gt_1 \quad (8)$$

According to the analysis:

$$2t_1 = t_2 \quad (9)$$

By equation (4) (7) (8) (9) we can know that:

$$\tan\alpha = \frac{gm}{2f} \quad (10)$$

By equation (10) the best take-off angle is related to athletes' weight and air resistance, according to the formula (10) we can calculate the optimum jumping angle is about 25 ° ~ 30 °by combining with the characteristics of Chinese athletes' body shape.

CONCLUSIONS

In the run-up phase, the Chinese athletes' speed is small. And in the last two steps of the run-up, the adjusting of the Chinese athletes' position decreases the take-off speed. In the whole process of the triple jump, the speed of the Chinese athletes is significantly smaller.

At the moment when the third jump lands, Chinese players' knee angle and the landing angle is too small, which makes the jumping power and speed decrease. In the triple jump final buffer phase, compared with the world's elite athletes, the magnitude of Chinese athletes' knee bending angle is significantly smaller. The reason is that the deformability and extending ability of the supporting legs is weak. The proportion of Chinese jumpers' stride jump and jump phase is larger than that of the world's top athletes, reflecting the lack of Chinese athletes' quickly stretching and kicking ability. Through the analysis and research on the best jumping angle for the third jump, for Chinese athletes the best jumping angle is 25 ° ~ 30 °. In addition, the action completion consistency and speed of Chinese athletes have insufficient, and the entire jumping process is too long.

Based on the above conclusions: (1) focus on speed training, increase the approach speed and improve the speed of the final step; (2) increase the stomp angle and knee angle during the jump process, improve the jumping force, the jump speed and the jump angle; (3) focus on training the leg muscles, increase the force of leg muscles in the triple jump process; (4) adjust the proportion of stride jump and jump in the whole process of triple jump, reduce the proportion of stride jump and jump.

In everyday life athletes need to strengthen the training of leg muscles and speed, but also need to improve the control ability of the body's balance, ensure the continuity of action, reduce the time of the whole process in order to better take advantage of the speed and obtain better performance.

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