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A Kinematic Study of Technical Characteristics in Elite Male Triple Jump Athletes in Zhejiang Province

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Abstract

This study analyzed the kinematic parameters of the triple jump in male athletes from Zhejiang Province's athletics team, using three-dimensional photography and the SIMI Motion 10.0 system. Key findings were: 1) Zhejiang Province's male triple jump athletes had an average stride length of 2.05 ± 0.15 m for the penultimate step and 2.14 ± 0.14 m for the last step in the approach run, with a 0.09 m difference. The penultimate step's center of mass averaged 8.32 ± 0.20 m/s in velocity, while the last step and take-off moment averaged 8.12 ± 0.25 m/s and 7.95 ± 0.14 m/s, respectively. 2) Significant correlations existed between kinematic parameters (landing instant velocity, take-off instant velocity, take-off instant vertical velocity) and triple jump performance across all phases. The strongest correlation was found between landing instant horizontal average velocity during the bound phase and athletes' triple jump performance ($\gamma = 0.97$, $P < 0.01$). Positive correlations were also observed between landing instant horizontal average velocity in the hop phase and take-off instant horizontal average velocity in the bound phase, with respective coefficients of $\gamma = 0.93$ and $\gamma = 0.90$ ($P < 0.05$). In summary, this study suggests that male triple jump athletes from Zhejiang Province should focus on improving their absolute speed during the approach run. Enhancing horizontal velocity during the hop phase's landing and take-off instant in the bound phase can contribute to enhancing triple jump performance.

Subject Areas

Sports Science

Keywords

Triple Jump, Stride Length, Technical Characteristics

1. Introduction

Triple jump is a highly demanding athletic discipline that consists of three consecutive phases: the hop, the bound, and the jump. All performed in a continuous sequence. The hop is a cyclical motion where an athlete jumps from one leg, cycles that leg through, and ends on the same leg on the runway. The subsequent step goes from the take-off leg to the opposite leg, and the final jump is similar to a long jump and starts from the non-take-off leg. Each of these phases must be learned and practiced to combine into a successful (long-distance) event. During the three take-off actions, triple jump athletes are exposed to increased injury risks due to high impact forces from the ground and strong muscle/tendon forces, which are further reflected in the internal loads on lower limb joints. Therefore, triple jump athletes not only need exceptional physical fitness but also must master sound and effective sports techniques [1] [2].

According to the principles of kinematics, each sports technique consists of various technical components, forming a "technical chain", wherein each component plays a different role in the application of the sports technique. These technical components are interrelated, interdependent, and collectively coordinate, connect, and unify [3]. Reviewing past studies on triple jump techniques, most of them have focused on the investigation of a specific phase of the triple jump, which appears relatively isolated and lacks comprehensive and coherent analysis [3] [4].

Hence, this paper takes the triple jump technique actions of five athletes from Zhejiang Province as the research subjects. It aims to explore the impact of the last two-step lengths, approach speed, take-off angle, and speed losses in each phase, and other metrics on athletes' triple jump performance. Ultimately, this research provides theoretical references for athlete training and technical improvement.

2. Research Subject and Methods

2.1. Research Subject

This study is based on the intra-team training matches of 5 male athletes from the Zhejiang Provincial Triple Jump Team in China. The main focus of the research is the technical movements of the athletes' best long jump performances. Please refer to **Table 1** for specific information.

Table 1. Overview of triple jump athletes' performance information.

Athlete ID	Level*	Training years (in years)
A	First Class	8
B	First Class	3
C	First Class	2
D	Second Class	2
E	Second Class	2

*First Class: Achieving a distance of 15.35 m in an official competition; Second Class: Achieving a distance of 13.60 m in an official competition.

2.2. Research Methodology

2.2.1. Three-Dimensional Photogrammetry Technique

At the competition venue, two Sony HDR-FX1000E digital cameras were strategically deployed, with their main optical axes configured at an approximate angle of 100˚. Precise calibration of the spatial dimensions encompassing the take-off board and the sand pit was meticulously executed using a specialized three-dimensional framework. Following calibration, camera positions remained unaltered, ensuring consistency in shooting conditions. The filming scope encompassed the athlete's approach run, the final three steps, and the landing phase within the sand pit. A filming frequency of 25 frames per second was maintained. To mitigate potential errors arising from camera movement, calibration of the sporting space was performed both prior to and following the competition, as exemplified in **Figure 1**.

2.2.2. Video Analysis Methodology

The SIMI Motion 10.0 three-dimensional motion analysis system was harnessed for the comprehensive scrutiny and dissection of three distinct jump variations: the hop, bound, and jump. Filming was conducted at an elevated sampling rate of 50 frames per second. Computational procedures entailed the derivation of three-dimensional spatial coordinates, achieved through the utilization of the DLT (Direct Linear Transformation) algorithm and sophisticated smoothing techniques. The Hanavan human body model was enlisted to facilitate the extraction of pertinent kinematic parameters.

2.2.3. Statistical Data Analysis

Accumulated kinematic data from athletes' training sessions and competitive performances were methodically curated. These datasets were meticulously categorized and organized employing the versatile Excel software. In-depth statistical analyses, encompassing both descriptive and comparative techniques, were carried out using the powerful SPSS 25.0 software package. These analytical endeavors culminated in the elucidation of pivotal findings and insightful conclusions.

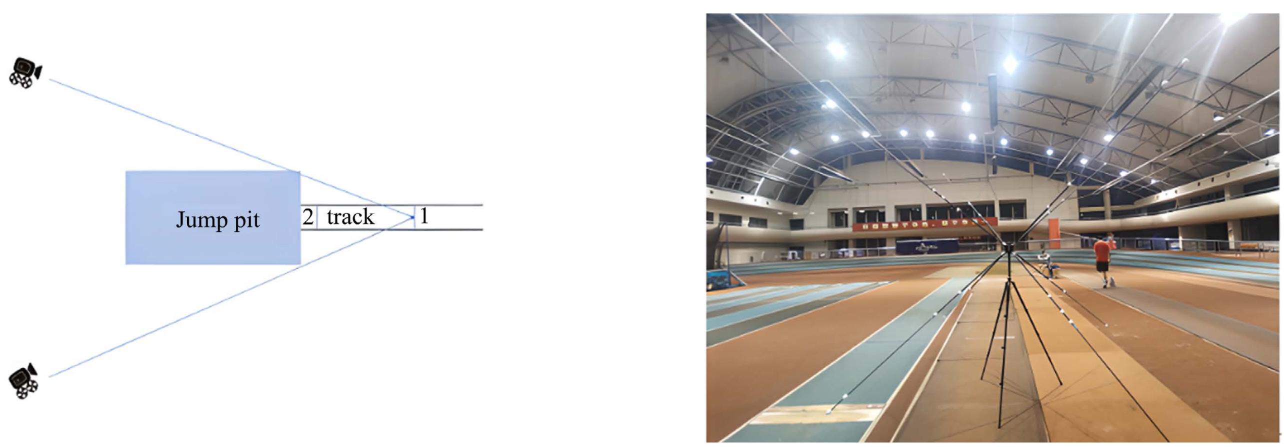

Figure 1. Schematic diagram of 3D photogrammetry method.

3. Result

3.1. Comparison of Kinematic Parameters before Take-Off

A comparison of parameters related to stride length and horizontal velocity is presented in Table 2. Elite male triple jump athletes from Zhejiang Province had an average stride length of 2.05 ± 0.15 m for the penultimate step and 2.14 ± 0.14 m for the last step. There was a difference of 0.09 m between these two. In contrast, elite male triple jump athletes from China had an average stride length of 2.50 ± 0.12 m for the last step and 2.54 ± 0.10 m for the penultimate step. During the final stage of the approach run, the average center of mass velocity for the last step and the penultimate step was 8.12 ± 0.25 m/s and 8.32 ± 0.20 m/s, respectively, with an take-off instant center of mass velocity of 7.95 ± 0.14 m/s. Chinese excellent male triple jump athletes achieved average center of mass velocities of 10.18 ± 0.31 m/s and 10.01 ± 0.21 m/s for the last two steps, with a take-off instant center of mass velocity of 9.44 ± 0.16 m/s.

3.2. Comparison of Athlete Take-Off Angles and Triple Jump Speed Parameters

3.2.1. Comparison of Speed Parameters in Three Phases of Jump

Elite male athletes from Zhejiang Province exhibited horizontal average velocities of 9.50 ± 0.74 m/s and 8.95 ± 0.53 m/s at the instant of the hop landing (V_{LO}) and take-off (V_{TO}), respectively, resulting in a speed loss of 0.55 ± 0.21 m/s. The vertical average velocity (V_V) of the center of mass at take-off was 2.87 ± 0.46 m/s. In contrast, Chinese elite athletes had vertical velocities at landing, take-off, and take-off instant of 9.67 ± 0.13 m/s, 9.27 ± 0.09 m/s, and 2.89 ± 0.11 m/s, respectively, with a notable difference. Athlete A's velocities for hop were 10.58 m/s, 9.65 m/s, and 3.41 m/s, which were comparable to those of Chinese elite athletes, but other four athletes showed relatively poorer performance.

Table 2. Comparison of stride length and horizontal velocity in the final two steps.

Athlete ID	Distance (m)	Stride length (m)		Center of mass velocity (m/s)		
		Last two steps	Last step	Last two steps	Last step	Take-off instant
A	15.35	2.04	2.21	8.48	8.20	8.06
B	14.45	2.20	2.07	8.37	8.18	8.10
C	15.05	1.94	2.30	8.41	8.36	7.97
D	13.80	1.88	2.18	8.36	8.31	7.86
E	13.50	2.21	1.94	7.97	7.72	7.75
X ± s	14.43 ± 0.79	2.05 ± 0.15	2.14 ± 0.14	8.32 ± 0.20	8.12 ± 0.25	7.95 ± 0.14
X ± s*	16.43 ± 0.23	2.54 ± 0.10	2.50 ± 0.12	10.18 ± 0.31	10.02 ± 0.21	9.44 ± 0.16

X ± s*: refers to the final two steps data of an elite male triple jump athlete from China.

In the bound phase, elite male triple jump athletes from China displayed horizontal average velocities of 9.06 ± 0.16 m/s and 8.46 ± 0.23 m/s at landing and take-off, respectively, resulting in a speed loss of 0.63 ± 0.12 m/s. The vertical average velocity of the center of mass at take-off was 2.75 ± 0.11 m/s. In contrast, athletes from Zhejiang Province exhibited vertical velocities of 8.46 ± 0.93 m/s, 8.69 ± 0.51 m/s, and 2.27 ± 0.21 m/s at landing, take-off, and take-off instant, respectively, indicating a significant difference.

In the jump phase, elite athletes from Zhejiang Province had average velocities of 7.50 ± 0.31 m/s at landing, 6.31 ± 0.68 m/s at take-off, and a vertical velocity of 2.25 ± 0.68 m/s at take-off, showing a difference compared to Chinese elite athletes (**Table 3**).

3.2.2. Comparison of Take-Off Angles

The angle between the center of mass's velocity vector and the horizontal plane during take-off is referred to as the take-off angle. **Table 4** illustrates that the take-off angle for the first jump (hop, a1) of elite male athletes from Zhejiang Province was 14.07˚ ± 1.99˚, while it was 15˚ ± 1.04˚ for Chinese elite male triple jump athletes, showing minimal difference. For the second jump (bound, a2), Zhejiang Province athletes had a take-off angle of 11.67˚ ± 1.75˚, whereas Chinese

Table 3. Speed of elite male triple jump athletes in Zhejiang province.

Athlete ID		A	B	C	D	E	X ± s	X ± s*
Hop (m/s)	V_{LO}	10.58	9.60	9.63	9.13	8.57	9.50 ± 0.74	9.67 ± 0.13
	V_{TO}	9.65	9.27	8.56	8.92	8.35	8.95 ± 0.53	9.27 ± 0.09
	V_V	3.41	3.23	2.34	2.48	2.92	2.87 ± 0.46	2.89 ± 0.11
Bound (m/s)	V_{LO}	9.89	8.74	9.04	8.14	7.41	8.64 ± 0.93	9.06 ± 0.16
	V_{TO}	9.34	8.48	9.11	8.10	8.44	8.69 ± 0.51	8.46 ± 0.23
	V_V	2.11	2.38	2.18	2.09	2.57	2.27 ± 0.21	2.75 ± 0.11
Jump (m/s)	V_{LO}	7.66	7.46	7.82	7.55	7.01	7.50 ± 0.31	7.90 ± 0.16
	V_{TO}	7.06	5.97	6.41	6.15	5.97	6.31 ± 0.68	6.58 ± 0.22
	V_V	1.14	2.44	2.15	2.94	2.57	2.25 ± 0.68	2.94 ± 0.38

X ± s*: represents the speed data of an elite Chinese male triple jump athlete's three jumps.

Table 4. Take-off angles of male triple jump athletes in Zhejiang province.

Athlete ID	A	B	C	D	E	X ± s	X ± s*
a1 (˚)	11.19	13.88	13.53	16.46	15.27	14.07 ± 1.99	15 ± 1.04
a2 (˚)	12.59	9.43	13.71	10.30	12.31	11.67 ± 1.75	14 ± 1.51
a3 (˚)	24.78	17.57	15.84	15.01	15.32	17.70 ± 4.08	21 ± 2.39

X ± s*: represents the angle data of an elite Chinese male triple jump athlete's three jumps.

elite athletes had an angle of 14˚ ± 1.51˚, indicating a noticeable difference. In the third jump (jump, a3), Chinese elite athletes achieved a take-off angle of 21˚ ± 2.93˚, while Zhejiang Province athletes had an angle of 17.70˚ ± 4.08˚, illustrating a distinct disparity. Athlete A had a take-off angle of only 11.19˚ for the first jump.

3.3. Correlation Coefficients between Take-Off Angles, Speed, and Performance

From the correlation analysis presented in Table 5, it is evident that landing instant speed, take-off instant speed, and take-off instant vertical speed in all three phases (hop, bound, and jump) exhibit significant correlations with triple jump performance. Notably, the correlation between the landing instant horizontal average velocity in the bound and triple jump performance was the highest (γ = 0.97, $P < 0.01$), while the hop landing instant horizontal average velocity, The bound take-off instant horizontal average velocity, and triple jump performance exhibited relatively high correlations (γ = 0.93, γ = 0.90, $P < 0.05$), all demonstrating positive associations. This suggests that the triple jump performance of athletes is closely related to the absolute speed during the approach phase.

3.4. Distance and Proportional Characteristics of Triple Jump by Athletes from Zhejiang Province

In the triple jump event, athletes are required to execute three distinct jumping forms—hop, bound, and jump—sequentially after a rapid approach run. Therefore, the precise management of distances between each jump is of paramount importance for achieving outstanding results. Table 6 reveals that excellent triple jump athletes from Zhejiang Province achieved an average distance of 14.43 meters, which significantly differed from the average distance of 16.43 meters achieved by elite male triple jump athletes from China. The average stride lengths for the three jumps by elite male athletes from Zhejiang Province were 4.9 meters, 4.63 meters, and 4.86 meters, respectively. In comparison, Chinese elite male triple jump athletes achieved average stride lengths of 6.03 meters, 4.64 meters, and 5.77 meters for the three jumps. The distances achieved in the bound phase were very close for both groups, but there was a noticeable difference in the distances achieved in the hop and jump phases.

Among the athletes from Zhejiang Province, Athlete A had a relatively larger proportion of distance in the jump phase, accounting for 35% of the total distance, compared to Athletes B, C, D, and E, who had 33%.

Table 5. Correlation coefficients between take-off angles, speed, and performance.

Phase	Hop (m/s)			a1˚	Bound (m/s)			a2˚	Jump (m/s)			a3˚
	V_{LO}	V_{TO}	V_V		V_{LO}	V_{TO}	V_V		V_{LO}	V_{TO}	V_V	
	0.93*	0.59	0.26	−0.90	0.97**	0.90*	−0.57	0.42	0.80	0.81	−0.84	0.72

*indicates significant difference with $P < 0.05$; ** indicates highly significant difference with $P < 0.01$.

Table 6. Analysis of the triple jump distance and percentage of elite athletes in Zhejiang province.

Athlete ID	Distances	Hop		Bound		Jump	
		Dis (m)	Pct (%)	Dis (m)	Pct (%)	Dis (m)	Pct (%)
A	15.35	5.09	33	4.91	33	5.35	35
B	14.45	4.99	35	4.68	35	4.79	33
C	15.05	4.98	33	4.84	33	5.23	35
D	13.80	4.78	35	4.36	35	4.56	33
E	13.50	4.75	35	4.36	35	4.39	33
Means	14.43	4.92	34.13	4.63	34.13	4.86	33.66
Means*	16.43	6.03	36.75	4.64	28.25	5.77	35.00

Means*: denotes the average data of elite Chinese male triple jump athletes.

4. Discussion

4.1. Analysis of Technical Features in the Pre-Take off Phase

The pre-takeoff phase, also known as the approach run, marks the beginning of the triple jump. Research suggests that the development of triple jump technique is closely associated with faster approach run speeds and refined jumping techniques. Consequently, speed has emerged as a crucial determinant of athlete performance [5]. Studies have shown that in the final stages of the approach run, a 1:3 ratio exists between approach run speed and jump performance. For every 0.1 m/s decrease in speed, there is a corresponding 0.30 m decrease in the final performance [4]. Hence, approach run speed plays a pivotal role in influencing the triple jump performance. Rapid approach run and powerful takeoff are essential factors for athletes to achieve outstanding results. Ideal takeoff speed and takeoff angle are also critical elements. The "last two steps" in the approach run, which serve as the crucial link between running and jumping, significantly impact the success of the approach run and are fundamental to speed utilization in the triple jump.

4.1.1. Comparison of the Length of the Last Two Steps before Take off

For outstanding male triple jumpers in Zhejiang province, the average length of the second-to-last step and the last step is 2.05 ± 0.15 m and 2.14 ± 0.14 m, respectively, with a slight difference of 0.09 m. This suggests that these athletes exhibit a "short-to-long" pattern in the length of their steps in the final phase of the approach run. On the other hand, elite male triple jumpers in China have an average length of 2.50 m for the last step and 2.54 m for the second-to-last step, with the second-to-last step being slightly longer, indicating a "long-to-short" pattern. Among Zhejiang's top athletes, only athlete B and athlete E display a "long-to-short" pattern, reducing their step lengths by 0.13 m and 0.27 m, respectively. Among them, athlete B maintains a relatively steady rhythm in the final phase of the approach run. Among the remaining three athletes, athlete A has the smallest variation in stride length at 0.07 m, while athlete C has the largest at 0.36 m. This suggests that athlete A has a stronger rhythm in the final phase of the approach run compared to the other two.

4.1.2. Comparison of Horizontal Velocity before Take off

Table 2 shows the variation in the center of mass horizontal velocity during the final phase of the approach run for elite long jumpers in Zhejiang province. In this phase, athletes' average horizontal velocity for the second-to-last step and the last step is 8.12 ± 0.25 m/s and 8.32 ± 0.20 m/s, respectively, with an average velocity at takeoff of 7.95 ± 0.14 m/s. This indicates that athletes in Zhejiang experience a gradual decrease in horizontal velocity in the final phase of the approach run. This phenomenon can be attributed to two main factors: athletes' relatively weak ability for rapid takeoff and poor ability to transition from running to jumping effectively. Consequently, they have to reduce their approach run speed to ensure proper execution of the takeoff technique. Additionally, elite male triple jumpers in China achieve significantly higher horizontal velocities in the last two steps, averaging 10.18 ± 0.31 m/s and 10.01 ± 0.21 m/s, with an average velocity at takeoff of 9.44 ± 0.16 m/s, which is much higher than their counterparts in Zhejiang province. This highlights that approach run speed is a critical factor limiting the triple jump performance of Zhejiang's elite athletes.

4.1.3. The Impact of Stride Length and Velocity on Performance

Research has shown a strong and significant correlation between the horizontal velocity of the center of mass before takeoff, the horizontal velocity at the moment of transitioning to the hop, and athletic performance [6]. Consequently, approach run speed is of paramount significance for athletes aiming to achieve outstanding results. The transition from running to jumping, known as the takeoff phase, plays a pivotal role in connecting the approach run technique with the jumping technique and, thus, has a decisive impact on performance. The length of the last two steps in the approach run determines the extent of speed loss during this phase. Therefore, stride length and velocity are positively correlated within a certain range and have a substantial influence on the triple jump performance.

4.2. Analysis of Takeoff Phase

The takeoff phase in triple jump is crucial for achieving greater distance. This section analyzes the technical characteristics during takeoff.

4.2.1. Analysis of Triple Jump Speed

Elite male athletes from Zhejiang province display significant differences in their horizontal average velocity and speed loss during the takeoff phase compared to China's top athletes. Athlete A achieves horizontal average velocities of 10.58 m/s, 9.65 m/s, and 3.41 m/s during the hop, the step-phase jump, and takeoff, respectively, which are comparable to China's elite athletes. However, the other four athletes demonstrate relatively lower performance. This variation in speed can be attributed to athletes' abilities to transition from running to jumping and their capacity to control horizontal velocity effectively. During takeoff, athletes convert a portion of their horizontal speed into vertical speed to protect lower limb muscles and ligaments from injury, resulting in a reduction in horizontal speed. Athletes with weaker abilities in leg extension and support tend to experience more significant speed loss. Thus, improving athletes' lower limb muscle capabilities for rapid extension and support, enhancing lower limb flexibility, and increasing their ability to withstand load during takeoff are crucial for achieving better performance.

4.2.2. Impact of Stride Length and Velocity on Performance

In the triple jump, the horizontal average velocity and angle of takeoff significantly correlate with the jump performance. Notably, the horizontal average velocity during the step-phase jump exhibits the highest correlation with jump performance ($\gamma = 0.97$, $P < 0.01$). The horizontal average velocity during the hop and the horizontal average velocity at takeoff during the step-phase jump also exhibit substantial correlations ($\gamma = 0.93$, $\gamma = 0.90$, $P < 0.05$), showing positive associations. This indicates that the triple jump performance is closely related to the absolute speed of the approach run, aligning with the views of scholars like Liu Shengjie [7] [8] [9]. Regarding takeoff angle, it is a crucial factor influencing the horizontal speed loss during the jump. However, due to the limited sample size, the correlation is not significant. Nevertheless, the influence of takeoff angle on triple jump performance cannot be overlooked.

4.3. Analysis of Distance and Proportion Characteristics in the Triple Jump

Triple jump athletes need to master the distances between each of the three jumps effectively to achieve outstanding results. Research has found that even though the world record holder in the triple jump, Jonathan Edwards, did not possess the best approach run or jumping technique, he excelled due to his optimal combination of the three jumps [10]. According to the research by Holmakov, athletes with fast approach runs ideally require a triple jump proportion of 35%, 30%, 35% [9]. James Hay, an American biomechanics expert, classified triple jump techniques into three types based on the proportion of each jump: single-leg, jumping, and balanced. Specifically, hopers have a percentage difference greater than 2% between single-leg jump and jumping, jumping types have a percentage difference greater than 2% between jumping and hop, and balanced types have a percentage difference of less than 2% between the two [11].

Table 6 reveals that Athlete A and Athlete C exhibit jumping-type techniques, while Athlete B, Athlete E, and Athlete D display single-leg jump techniques. This pattern contrasts with the majority of elite athletes worldwide who primarily employ a balanced technique. The main reasons for this discrepancy can be attributed to the limited understanding of the essential principles of the triple jump in Zhejiang's elite athletes. Athletes often emphasize the distance covered in the hop excessively, leading to excessive energy expenditure and insufficient speed for the step-phase jump and the jump itself, ultimately affecting their triple jump performance. Additionally, the rapid extension ability and support capacity of the lower limb muscles are weaker in Zhejiang's elite athletes, resulting in significant speed loss during each jump. Therefore, in training, it is essential to enhance athletes' understanding of the fundamental principles of the triple jump and improve the rhythmic aspect of the three jumps. Furthermore, increasing athletes' ability to move quickly, extend rapidly, and strengthen their lower limb muscles to endure loads can enhance the transition between running, hoping, step-phase jumping, and the jump, resulting in more efficient speed and energy utilization during the triple jump [12].

5. Conclusions

1) Elite male long jumpers in Zhejiang province exhibit significant differences in their technical characteristics during the pre-takeoff phase compared to China's elite male triple jumpers. Specifically, their last step is slightly longer than the second-to-last step, resulting in a smaller takeoff angle. Additionally, their absolute speed during the approach run phase is weaker. Therefore, it is crucial to enhance athletes' stride training in the approach run phase and improve their absolute speed to effectively improve their performance.

2) In terms of speed and angle during the three jumps, Zhejiang's elite athletes experience significantly higher speed loss compared to China's elite athletes, indicating higher energy loss. The primary reasons include technical deficiencies in the triple jump technique, prolonged transition time between each jump, and weak lower limb muscle support and extension capabilities. Therefore, it is imperative to strengthen athletes' lower limb muscles' support and extension capabilities and focus on training to improve the transition from running to jumping, resulting in more economical speed and energy utilization.

3) Most elite male triple jumpers in Zhejiang province predominantly employ a "hop" technique, which deviates from the global trend towards a more balanced technique. This can be attributed to their limited understanding of the essential principles of the triple jump. Athletes often place excessive emphasis on the distance covered during the hop, leading to excessive energy expenditure and insufficient speed for subsequent jumps. Additionally, their lower limb muscle groups exhibit poor rapid extension and support capabilities, resulting in significant speed loss during each jump. Therefore, athletes should be guided to understand the fundamental principles of the triple jump and to select a triple jump proportion suitable for their physical condition. This will lead to a more economical and efficient triple jump performance.

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Conflicts of Interest

The authors declare no conflict of interest.

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