Special Take-Off Technical Diagnosis of Zi'ang Dong, the Gymnasiade Champion in Men's High Jump

Jiawei Liu, Tinggang Yuan(✉), and Jinbao Hou

China Institute of Sport Science, Beijing, China
yuantinggang@ciss.cn

Abstract. In the case study of Dong's techniques, and make suggestions for him and other athletes to help improve the overall high jump level. And, help promote the construction of education informatization. This thesis uses Video shooting, Digital modeling and other research methods. Conclusion: (1) Dong's technical characteristics include: First, the relative values of H0 and H1 are great, and the take-off time is short in the take-off stage. Second, the knee angle of the take-off leg is large at touch-down, and the muscle flexibility and plyometric contraction are excellent. Fourth, the swing leg swings fast. (1) Dong's technical weaknesses include: First, the take-off leg support is weak. Second, the velocity conversion rate is low, the vertical velocity is slow, the flight angle is small, and the vertical working distance of the center of mass is short in the take-off stage. Third, the economy of bar clearance is below expectation. (3) The reasons for Dong's failed jumps include: First, the velocity conversion rate drops in the take-off stage. Second, the maximum swing speed of the swing leg decreases, and the folding degree and braking height are insufficient at take-off. Third, the knee extension of the take-off leg is not enough, and the hip and knee are not fully stretched at take-off. In the take-off training of teenage high jumpers, it is advised to: make the extension-swing coordination more consistent, coherent, and stable to improve the velocity conversion rate while strengthening the supporting and extension abilities of the take-off leg and the rapid swing and high swing braking abilities of the swing leg; and adjust the take-off distance based on the horizontal distance between an athlete's highest point and the bar (HD), the decline in which suggests higher bar clearance efficiency and H2 utilization, to reduce the likelihood of failure.

Keywords: track and field · high jump · kinematic analysis · Digital modeling

1 Introduction

Born in Jiangsu Province in 2005, Dong won the gold medal in the 14th National Student Sports Games in 2021 with a score of 2.24 m. In the 19th Gymnasiade in 2022, he stood out with 2.09 m and won the title. In the case study of Dong's techniques, we first identified his weaknesses and offered specific suggestions to make his training more targeted. Next, we established an individual database through continuous monitoring

V. Balakrishnan et al. (Eds.): ICMEIM 2022, AHSSEH 6, pp. 839–847, 2022.
https://doi.org/10.2991/978-94-6463-044-2_105

and explored Dong's technical characteristics and styles to complete his training more personalized. Finally, we provided a reference for the technical analysis and training optimization for other athletes to help improve the overall high jump level.

2 Research Objects and Methods

2.1 Research Objects

We took Dong's techniques in his 12 jumps from 2021 to 2022 as research objects (Table 1) and compared them with 7 Chinese elite athletes' techniques (The Mean ± SD of the results is 2.21 ± 0.02 m) in their nine jumps [1].

2.2 Research Methods

2.2.1 Literature Review

The papers, reports, and other literature on high jump technical analysis were reviewed through platforms such as CNKI, Web of Science, and the IAAF.

2.2.2 Video Shooting

Three high-speed SONY cameras at 100 Hz were positioned at 0°, 90° and 130° of the high jump pad. One standardised calibration procedure was conducted before and after the commencement of the events on the evening of the high jump. Specifically, a rigid cuboid calibration frame was filmed on the high jump run-up/take-off area and repositioned multiple times over discrete predefined areas. This ensured an accurate defined

Table 1. Information on Dong's jumps

Name	PB/m	Result/m	Date-Venue (Mark)
Zi'ang DONG	2.24	2.15	15 MAY 2021-Nanjing (A)
		2.00	05 MAR 2022-Nanjing (B)
		2.10	
		2.20-1F	
		2.20-2F	
		2.00	24 MAR 2022-Nanjing (C)
		2.05	
		2.10	
		2.15m-1F	
		2.15m-2F	
		2.15m-3F	
		2.05	03 MAY 2022-Nanjing (D)

Note: F denotes a failed jump.

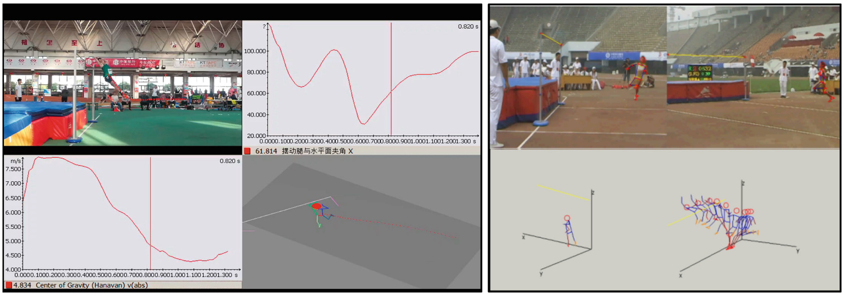

Fig. 1. Engineering drawing of digital model construction

volume for athletes who approached the uprights from both left and right directions. This approach produced a large number of non-coplanar control points per individual calibrated volume and facilitated the construction of a three-dimensional global coordinate system.

2.2.3 Digital Modeling

The video files were imported into SIMI Motion version 9.2.2 and was manually digitised by a single experienced operator to obtain kinematic data. The video files were imported into SIMI Motion (SIMI Motion version 9.2.2, Simi Reality Motion Systems GmbH, Germany) and the highest successful attempt for each athlete was manually digitised by a single experienced operator to obtain kinematic data. An event synchronisation technique (synchronisation of four critical instants) was applied through SIMI Motion to synchronise the two-dimensional coordinates from each camera involved in the recording. Digitising started 15 frames before the beginning of the first touchdown and ended 15 frames after the required sequence to provide padding during filtering. Each file was first digitised frame by frame and upon completion adjustments were made as necessary using the points over frame method, where each point was tracked through the entire sequence. The Direct Linear Transformation (DLT) algorithm was used to reconstruct the real-world 3D coordinates from individual camera's x and y image coordinates. Reliability of the digitising process was estimated by repeated digitising of one full trial with an intervening period of 48 h. The results showed minimal systematic and random errors and therefore confirmed the high reliability of the digitising process. De Leva's (1996) body segment parameter models were used to obtain data for the whole body centre of mass and for key body segments. A recursive second-order, low-pass Butterworth digital filter (zero phase-lag) was employed to filter the raw coordinate data. The cut-off frequencies were calculated using residual analysis [2] (Fig. 1).

2.2.4 Mathematical Statistics

SPSS 23 was used on data for normality analysis, difference analysis, and descriptive statistics. The Kolmogorov-Smirnov and Shapiro-Wilk normality tests show that $p > 0.05$, indicating that the data is normally distributed. The independent sample T-test was conducted on the normally distributed data for difference analysis—the Mann-Whitney U test on the not normally distributed data, revealing significant differences at $p < 0.05$.

2.2.5 Comparative Analysis

We compared Dong with Chinese elite athletes to explore his technical weaknesses and characteristics. Besides, we compared his successful and failed jumps to figure out the reasons for his failed attempts and offered suggestions based on his technical weaknesses and the factors leading to his jump failures.

3 Research Results

3.1 Parameter of the Center of Mass Height

Dong's mean relative values of H0 and H1 are both greater than the control group. His working distance and H2 are 0.03 m less than the control group, respectively, and there are significant differences in the relative values of H0 and H1 and the variation ratio between H0 and H1. It can be concluded that, compared with the control group, Dong does worse in the vertical working distance of the center of mass and H2 in the process from touch-down to take-off (Table 2).

The mean H0, H1, and working distance are less in Dong's failed jumps than in his successful jumps. Although there is no statistical difference, the vertical working distance of the center of mass is Dong's weak and unstable aspect in his take-off technique, so it can be concluded that H0, H1, and working distance are the factors leading to his failed jumps. Dong's mean H3 in his successful jumps is up to 0.15 m, far higher than 0.03 m for the control group. Dong's highest point of the center of mass reaches 2.27 m, but he fails many times at 2.15 m and 2.20 m, and his mean HD is 18.47 cm in his successful jumps. Based on the above information, it is noted that, although Dong can reach a high center of mass, the horizontal distance is large between the highest point of the center of mass and the bar, so he cannot make full use of his highest center of mass to cross the

Table 2. Data on take-off center of mass height

Athlete	Mean ± SD	H0 /m	ΔH0 /%	H1 /m	ΔH1 /%	ΔVariation/%	Working Distance/m	H2 /m	H3 /m	HD /cm
Dong (S)	(n = 7)	0.94 ± 0.04	49.86 ± 1.93	1.30 ± 0.03	68.91 ± 1.66	38.30 ± 3.32	0.36 ± 0.02	0.92 ± 0.07	0.15 ± 0.07	18.47 ± 9.27
CG	(n = 9)	0.91 ± 0.04	47.18 ± 0.92	1.29 ± 0.06	67.22 ± 1.70	42.5 ± 3.49	0.39 ± 0.03	0.95 ± 0.05	0.03 ± 0.02	-
Dong (F)	(n = 5)	0.92 ± 0.05	48.91 ± 2.65	1.27 ± 0.03	67.47 ± 1.58	38.14 ± 5.24	0.35 ± 0.03	0.92 ± 0.05	48.91 ± 2.65	1.27 ± 0.03

Note: H0 denotes the vertical center of mass height above the ground at touch-down; H1 denotes the vertical center of mass height above the ground at take-off; H2 denotes how high the mass of the center rises after take-off; H3 denotes the vertical distance between the highest point of the center of mass and the bar; HD denotes the horizontal distance between the highest point of the center of mass and the bar; Working Distance denotes the distance between H0 and H1.

Table 3. Data on Dong's successful and failed jumps

Result/m	CM-foot distance at TD/m	Take-off Distance/m	Take-off Width/m	Take-off Time/s				
				Total	Flexion	Proportion/%	Extension	Proportion/%
S (n = 7)	0.57 ± 0.03	0.78 ± 0.09	0.43 ± 0.14	0.13 ± 0.01	0.07 ± 0.02	50.68 ± 9.40	0.07 ± 0.01	49.32 ± 9.40
F (n = 5)	0.60 ± 0.03	0.93 ± 0.10	0.40 ± 0.23	0.14 ± 0.01	0.08 ± 0.03	59.29 ± 13.74	0.06 ± 0.02	40.71 ± 13.74

Note: CM-foot distance at TD denotes the horizontal distance (resultant) between the CM and plant foot CM at the instant of TD during the take-off phase; Take-off Distance denotes the vertical distance between the take-off point and the bar; Take-off Width denotes the vertical distance between the take-off point and the near pole.

bar. In general, there is a distinct gap in the bar clearance economy between Dong and the control group.

3.2 Take-Off Relative Position and Time

The mean Take-off time for the control group is 0.15 s, 0.02 s more than Dong with a significant difference, which indicates that Dong is able to Take-off time in a short time. According to Dong's Take-off time is stable in general; Flexion time accounts for about 50% in his successful jumps, but it increases in his failed jumps. Concerning the horizontal distance between the center of mass and the take-off ankle at touch-down, it increases by 3 cm on average in his failed jumps, but there is no significant difference. Regarding the take-off distance, it is 15 cm larger in his failed jumps than in his successful jumps, with a substantial difference. Therefore, it can be concluded that the increase in take-off distance is one of the factors leading to his failed jumps (Table 3).

3.3 Take-Off Speed and Flight Angle

Compared with the control group, Dong's mean take-off Angle is 4.17° smaller with a significant difference; his mean vertical take-off velocity is 0.35 m/s slower with a significant difference; his mean horizontal take-off velocity is 0.31 m/s faster, and his mean velocity conversion rate is 3.98% lower, with significant differences in the data. It shows that Dong is weak in converting the horizontal velocity at touch-down to the vertical velocity at take-off in the Take-off stage. Dong's vertical velocity at touch-down is positive in 7 successful jumps, suggesting the existence of an upward vertical velocity; the mean vertical velocity of the control group is -0.14 ± 0.18 m/s, 0.54 m/s slower than Dong's. Given the significant difference in the data, it can be concluded that the upward vertical velocity at touch-down in the take-off stage is Dong's own technical characteristic (Table 4).

Compared with Dong's successful jumps, his horizontal velocity increases, and his vertical velocity decreases at touch-down in the take-off stage in his failed jumps, with significant differences in the data. While increasing the horizontal velocity, Dong reduces

Table 4. Data on take-off speed and flight angle

Athlete	Mean ± SD	Take-off Angle/°	Speed/(m/s)					
			Vh-TD	Vv-TD	Vh-TO	Vv-TO	Vr	Velocity Conversion Rate/%
Dong (S)	(n = 7)	43.48 ± 1.64	7.16 ± 0.05	0.40 ± 0.18	4.56 ± 0.21	4.32 ± 0.12	6.26 ± 0.16	60.34 ± 1.60
CG	(n = 9)	47.66 ± 2.37	7.24 ± 0.31	-0.14 ± 0.18	4.26 ± 0.34	4.67 ± 0.19	6.32 ± 0.27	64.31 ± 2.38
Dong (F)	(n = 5)	41.62 ± 2.54	7.45 ± 0.17	0.13 ± 0.18	4.68 ± 0.24	4.15 ± 0.18	6.26 ± 0.12	55.75 ± 2.95

Note: Vh denotes horizontal velocity; Vv denotes vertical velocity; Vr denotes resultant velocity; TD denotes touch-down; TO denotes take-off; Velocity Conversion Rate denotes the ratio of vertical velocity (TD-TO) conversion to the horizontal velocity of TD (same below).

Table 5. Data on Dong's successful and failed jumps

Mean ± SD	Swing Leg			
	AVmax /(°/s)	Vv-TO /(m/s)	Fold Angle/°	Swing Angle/°
S (n = 7)	763.32 ± 29.77	4.56 ± 0.27	67.03 ± 6.87	14.23 ± 3.69
F (n = 5)	699.98 ± 45.43	4.47 ± 0.28	70.17 ± 3.57	14.33 ± 2.59

Note: AVmax denotes the maximum angular velocity; Vv-TO denotes the vertical velocity at take-off; Fold Angle denotes the knee angle at take-off; Swing Angle denotes the angle between the hip-knee line and the horizontal plane at take-off.

the vertical velocity at touch-down in the take-off stage. In his failed jumps, the mean horizontal velocity increases by 0.12 m/s, the mean vertical velocity decreases by 0.17 m/s, and the mean velocity conversion rate decreases by 4.59% with a significant difference at take-off in the take-off stage. Due to the less velocity conversion, the horizontal velocity fails to be effectively converted into the vertical velocity and affects the flight angle. It can be concluded that the vertical velocity maintained at about 0.40 m/s at touch-down in the take-off stage is his personalized technical characteristic; while the weakening of this technical characteristic, the pursuit of faster horizontal velocity at touch-down in the take-off stage, and the low-velocity conversion rate in the take-off stage are the factors leading to his failed jumps [3].

Table 6. Data on Dong's successful and failed jumps

Mean ± SD	Take-off Leg/°						
	Hip Angle		Knee Angle			Ankle Angle	
	TD	TO	TD	Lowest	TO	TD	TO
S (n = 7)	159.83 ± 2.66	175.7 ± 1.81	163.74 ± 1.43	150.45 ± 6.65	170.15 ± 3.1	121.81 ± 3.34	136.74 ± 5.5
F (n = 5)	155.01 ± 3.18	168.49 ± 4.48	160.48 ± 3.7	142.44 ± 8.59	161.27 ± 10.68	122.07 ± 2.06	138.54 ± 7.55

3.4 Parameters of Swing Leg and Take-Off Leg

The mean maximum swing angular velocity in Dong's successful jumps is up to 763.32°/s, much higher than 474.30°/s for the control group, with a significant difference. The mean maximum swing angular velocity in his failed jumps is 699.98°/s, still higher than 225.68°/s for the control group, showing a significant difference compared with the data on his successful jumps. It can be concluded that the rapid swing of the swing leg is his prominent technical characteristic, while the decline in swing speed is one of the factors leading to his failed jumps (Tables 5 and 6).

Dong's knee angles at touch-down, with the lowest, and at take-off are larger than the control group in his successful jumps with significant differences in the data. Among them, the knee angle with the lowest shows the most distinct difference. A sizeable supporting knee angle helps to lower the center of mass and increase the vertical working distance, so as to prepare for extension in the take-up stage. In contrast, a large lowest angle reflects poor leg support and is not conducive to the rapid completion of the extension. Compared with Dong's lowest angle, his extension angle increases by 48.24%, much higher than 27.41% for the control group. In brief, Dong's full extension demonstrates his excellent muscle flexibility and plyometric contraction [4].

Compared with Dong's successful jumps, the knee angles at touch-down, with lowest, and at take-off are smaller in his failed jumps. The extension angle merely increases by 4.36% over the lowest angle, 43.89% lower than that in his successful jumps. The data shows significant differences. Therefore, the following two factors can partly account for Dong's failed jumps: smaller supporting angle and insufficient lowest due to less toughness in the hips, knees, and surrounding muscles; insufficient extension due to lack of joint stretch and muscle strength [5].

4 Conclusions and Suggestions

4.1 Conclusions

- Dong's technical characteristics include: First, the relative values of H0 and H1 are great, the upward vertical velocity at touch-down is up to 0.40 m/s, and the take-off time is short in the take-off stage. Second, the knee angle of the take-off leg is large at touch-down, and the muscle flexibility and plyometric contraction are excellent.

Third, the swing leg swings fast, with the mean maximum angular velocity of about 763.32°/s.

- Dong's technical weaknesses include: First, the take-off leg support is weak, mainly at the moment of lowest in the take-off stage. Second, the velocity conversion rate is low, the vertical velocity is slow, the flight angle is small, and the vertical working distance of the center of mass is short in the take-off stage. Third, the economy of bar clearance is below expectation, the utilization of H2 is low, the mean H3 is 0.15 m, and the mean HD is 18.47 cm.
- The reasons for Dong's failed jumps include: First, the velocity conversion rate drops in the take-off stage, with the horizontal velocity about 0.30 m/s faster, the vertical velocity 0.17 m/s slower, and the flight angle 4.17° smaller. Second, the maximum swing speed of the swing leg decreases, and the folding degree and braking height are insufficient at take-off. Third, the knee extension of the take-off leg is not enough, and the hip and knee are not fully stretched at take-off.

4.2 Suggestions

In the take-off training of teenage high jumpers, it is advised to: make the extension-swing coordination more consistent, coherent, and stable to improve the velocity conversion rate while strengthening the supporting and extension abilities of the take-off leg and the rapid swing and high swing braking abilities of the swing leg; and adjust the take-off distance based on the horizontal distance between an athlete's highest point and the bar (HD), the decline in which suggests higher bar clearance efficiency and H2 utilization, to reduce the likelihood of failure.

References

1. Cheng H. R. A Kinematic Study on the Key Technical Characteristics of Chinese Active Elite Male High Jumpers [D]. *China Institute of Sport Science*, 2020.
2. Nicholson, G., Bennett, T. D., Bissas, A. and Merlino, S.. Biomechanical Report for the IAAF World Indoor Championships 2018: High Jump Men [J]. Birmingham, UK: International Association of Athletics Federations, 2019, (1):1-42.
3. Lu C. G., Huang Z. & Liu Z. Q. A Study on the Technical Characteristics of Chinese High Jumper Haiqiang Huang [J]. *Sichuan Sports Science*, 2008, (4): 60-63.
4. Liu J. Biomechanical Study on Affecting Mechanism of Take-off Effect at Different Run-up Speeds [J]. *Journal of Shenyang Sport University*, 2003, (2): 90-92, 110.
5. Lv T. & Liu S. J. Kinematic Analysis of the Bar Clearance Technique of Chinese Female High Jumpers [J]. *Journal of Beijing Sport University*, 2010, 33(11): 131-133, 144.