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Article

Analysis of rhythmic movement techniques in female college long jump athletes: Insights from athletics open

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Abstract: This study aims to investigate the kinematic characteristics of the long jump in female college athletes. Video data from 10 Asian female college athletes in the Athletics Open Long Jump Competition were analyzed using high-speed digital cameras with a 240 Hz sampling rate. The captured footage was processed through motion analysis software, with joint markers manually digitized. The results showed that during the rhythmic movement phases, both the horizontal and resultant velocity of the center of gravity and the hip joint angle increase at the heel strike of the swing leg. However, at the toe-off of the swing leg, vertical velocity, angle, and height of the center of gravity decrease, leading to a reduction in flight distance. At the heel strike of the take-off leg, the center of gravity height decreases, and the ankle joint angle increases. At the toe-off of the take-off leg, both the resultant velocity of the center of gravity and the hip and ankle joint angles increase. This method allows coaches to use video analysis to guide athletes in refining their technique, ultimately improving performance and coaching efficiency.

Keywords: biomechanics; sport performance; track and field; kinematics

1. Introduction

The long jump is a field event, and its technical movements can be categorized into four phases: the run-up, take-off, flight, and landing [1]. In long jump competitions in the past, the ability to combine the run-up velocity and vertical velocity between jumps is critical to optimizing long jump performance [2–5]. In addition to maintaining the horizontal velocity during the run-up, it is also necessary to lower the height of the gravity center and adjust the body movement to prepare for take-off [6]. To achieve excellent performance, athletes must effectively convert horizontal velocity into vertical velocity while minimizing the loss of horizontal velocity. This process requires precise coordination of the body's movements, ensuring an optimal take-off angle and maximizing the force generated during the jump. By maintaining a balance between horizontal speed and vertical lift, athletes can enhance their jump distance and overall performance. Proper technique, strength, and timing are crucial in achieving this efficient conversion of energy during the jump [7–9]. With the optimal resultant velocity, angle, height of the gravity center, and a particular projection angle, the large horizontal and vertical velocities are the key factors for the long jump distance [10–15]. An athlete's overall performance is primarily determined by the resultant velocity, take-off angle, and the height of the center of gravity during the take-off phase [16].

In order to methodically realize the movement pattern of a long jump, it can be rationally divided into three stages (**Figure 1**); (i) the swing leg support stage: the period from the heel strike of the swing leg to the toe-off of the swing leg; (ii) the flying stage: the period from the toe-off of the swing leg to heel strike of the take-off leg; (iii) the take-off leg support stage: the period from the heel strike of the take-off leg to the toe-off of the take-off leg [4,5,10–14,17–19].

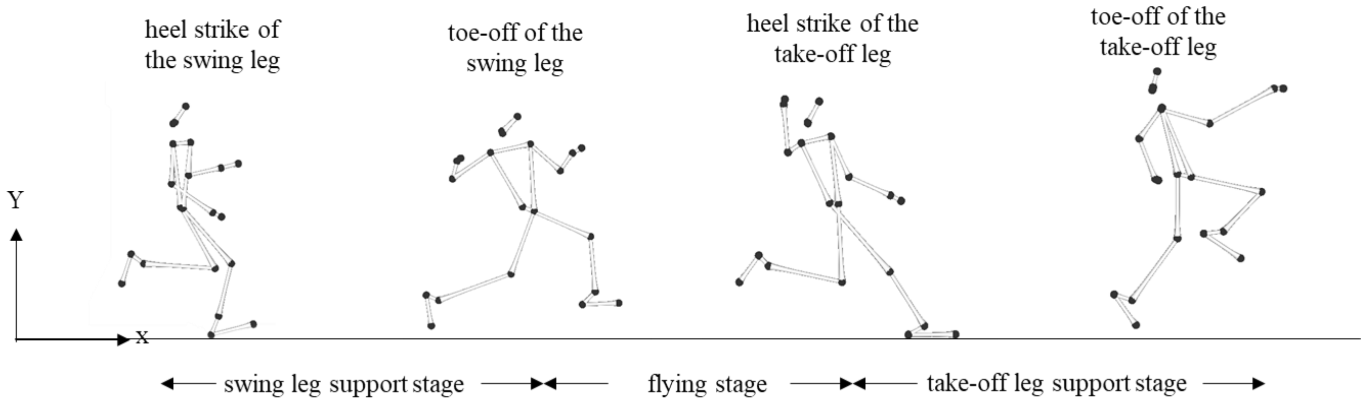

Figure 1. Definition of the stage.

The purpose of this study is to analyze the movement techniques of high-level Asian female long jump athletes to identify key biomechanical factors influencing performance. By utilizing video-based technique analysis, this study aims to provide insights for coaches to enhance training efficiency and optimize athletes' performance.

2. Materials and methods

2.1. Participants

This represents a retrospective study. Video data of 10 Asian female college athletes in the 2015 Taipei Athletics Open Long Jump Competition are carefully analyzed. The average age, average height, and average weight of the athletes in order are 21 ± 3 years, 1.63 ± 0.05 m, and 55.60 ± 3.44 kg, respectively. Further, the average long jump result was reported to be 5.20 ± 0.24 m. The athlete's personal information is removed, and images are processed through mosaics to ensure compliance with the Helsinki Declaration.

2.2. Experimental instruments and materials

In this study, the filming was performed in an actual open competition, and the venue was arranged after the referee's permission was sought before the competition began. A high-speed digital camera (sampling rate = 240 Hz, Sony, HDR-AX2000, Japan) was set up at locations 12 m from the center of the coordinate frame. A plane coordinate frame 5 × 2 m (length × width) in size and including 14 markers was set up with its origin at the center of the take-off board to construct a coordinate system before data collection. The cameras (specifically, the optical axes of their lenses) were pointed at the center of the coordinate system setup; the image can cover the range of a plane coordinate frame. Then, after removing the plane coordinate frame, the performance of the long jumper during the whole process from the moment when the heel strike of the swing leg to the toe-off of the take-off leg is filmed, and then the best long jump performance is selected for analysis (**Figure 2**).

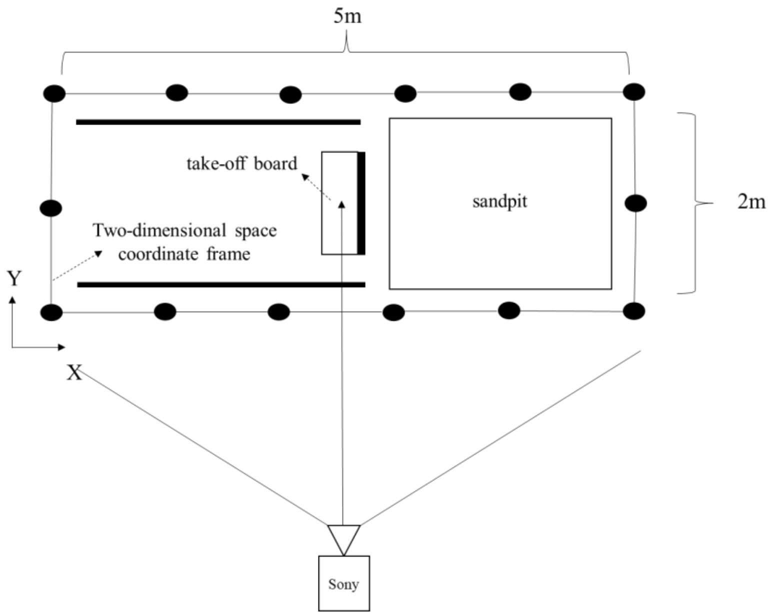

Figure 2. Shooting diagram.

2.3. Data processing

The captured images were analyzed using the Kwon3D motion analysis suite (Visol, Inc., Kyonggi-do, Korea). In the global coordinate system, the *X* and *Y* axes corresponded to the forward-backward and vertical (upward-downward) directions, respectively. Limb parameters were defined based on previous studies, with key joint positions identified at the head, both ears, shoulders, elbows, wrists, middle fingertips, hips, knees, ankles, heels, and toes—resulting in a total of 21 joint points [20]. These were grouped into 14 limb segments: Head and neck, trunk, right and left upper arms, forearms, palms, thighs, calves, and soles of the feet. Define each center of gravity and angle. The velocity of the center of gravity is the resultant velocity $\overrightarrow{Rv}$ of the horizontal velocity $\vec{V_x}$ and the vertical velocity $\vec{V_y}$, the angle of the center of gravity between the horizontal velocity $\vec{V_x}$ and the resultant velocity $\overrightarrow{Rv}$, the height of the center of gravity is the vertical height in the sagittal plane. Hip joint angle (the angle of the lines connecting the shoulder to the hip joint and the hip to the knee joint), knee joint angle (the angle of the lines connecting the hip to the knee joint and the knee to the ankle joint), ankle joint angle (the angle of the lines connecting the knee to the ankle joint and the ankle to the toe (**Figure 3**). The data were filtered by applying the 4th butterworth low pass filter with the cut-off frequency at 6 Hz before all kinematic parameters were calculated [21–23].

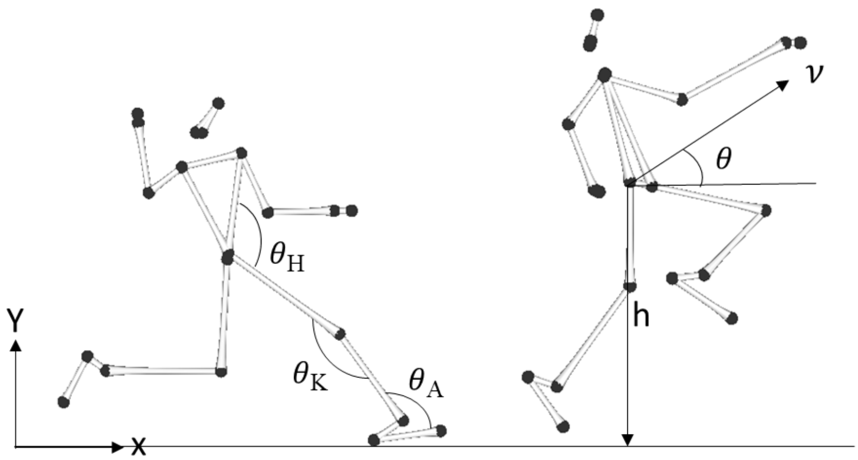

Figure 3. Schematic diagram of the gravity center and the joint angle.

Note: θH: hip joint angles; θK: knee joint angles; θA: ankle joint angles; ν: velocity of the gravity center; θ: angle of the gravity center; h: height of the gravity center.

2.4. Statistical analysis

SPSS 17 was used for data analysis. After exploratory analysis, data were normally distributed. Kinematic parameters were expressed in the form of mean ± standard deviation. Pearson product-moment correlation coefficient was used to test the correlation of various parameters. The level of significance was set at $\alpha = 0.05$.

3. Results

By analyzing the performance of the long jump and the temporal parameters of each stage, it is realized that the time of the flying stage is negatively correlated with the long jump distance ($r = -0.687$, $p = 0.028$) (**Table 1**).

Table 1. The performance of the long jump and the parameters of each stage. $N = 10$.

	Mean ± SD	*p*	*r*	
performance of the long jump				
long jump distance (m)	5.20 ± 0.24	-	-	
temporal parameters of each stage				
the swing leg support stage (s)	0.12 ± 0.01	0.802	−0.091	
the flying stage (s)	0.08 ± 0.02	0.028	−0.687	*
the take-off leg support stage (s)	0.13 ± 0.01	0.544	−0.219	
the period from the swing leg support stage to the take-off leg support stage (s)	0.32 ± 0.03	0.128	−0.515	

*$p < 0.05$.

Analysis of the relationship between the performance of the long jump and the kinematic parameters of the gravity center indicates that the horizontal velocity of the gravity center at the heel strike of the swing leg is positively correlated with the long jump distance ($r = 0.733$, $p = 0.016$). The vertical velocity of the gravity center at the toe-off of the swing leg is negatively correlated with the distance ($r = -0.745$, $p = 0.013$). There exists a positive correlation between the resultant velocity of the gravity center at the heel strike of the swing leg and the long jump distance ($r =$

0.733, $p = 0.016$). Additionally, there is a positive link between the resultant velocity of the gravity center at the toe-off of the take-off leg and the long jump distance ($r = 0.673$, $p = 0.033$). Furthermore, the angle of the gravity center at the toe-off of the swing leg is significantly negatively correlated with the long jump distance ($r = -0.794$, $p = 0.006$). The height of the gravity center at the toe-off of the swing leg is negatively correlated with the long jump distance ($r = -0.636$, $p = 0.048$). Lastly, the height of the gravity center at the heel strike of the take-off leg is negatively linked to the long jump distance ($r = -0.758$, $p = 0.011$) (**Table 2**).

Table 2. Performance of long jump and kinematic parameters of gravity center of each stage. $N = 10$.

	Mean ± SD	***p***	***r***	
horizontal velocity of the gravity center (m/s)				
heel strike of the swing leg	7.78 ± 0.98	0.016	0.733	*
toe-off of the swing leg	8.27 ± 0.34	0.060	0.612	
heel strike of the take-off leg	8.40 ± 0.27	0.425	0.285	
toe-off of the take-off leg	6.95 ± 0.99	0.082	0.576	
vertical velocity of the gravity center (m/s)				
heel strike of the swing leg	−0.20 ± 0.47	0.751	−0.115	
toe-off of the swing leg	0.22 ± 0.17	0.013	−0.745	*
heel strike of the take-off leg	−0.16 ± 0.18	0.074	0.588	
toe-off of the take-off leg	2.05 ± 0.44	0.074	0.588	
resultant velocity of the gravity center (m/s)				
heel strike of the swing leg	7.79 ± 0.98	0.016	0.733	*
toe-off of the swing leg	8.27 ± 0.33	0.060	0.612	
heel strike of the take-off leg	8.41 ± 0.27	0.425	0.285	
toe-off of the take-off leg	7.25 ± 1.02	0.033	0.673	*
angle of the gravity center (°)				
heel strike of the swing leg	−1.50 ± 3.19	0.676	−0.152	
toe-off of the swing leg	1.54 ± 1.23	0.006	−0.794	**
heel strike of the take-off leg	−1.10 ± 1.25	0.074	0.588	
toe-off of the take-off leg	16.42 ± 3.09	0.533	0.224	
height of the gravity center (m)				
heel strike of the swing leg	0.96 ± 0.04	0.098	−0.552	
toe-off of the swing leg	0.97 ± 0.04	0.048	−0.636	*
heel strike of the take-off leg	0.96 ± 0.04	0.011	−0.758	*
toe-off of the take-off leg	1.11 ± 0.03	0.090	−0.564	

*$p < 0.05$; **$p < 0.01$.

The kinematic analysis results reveal that the hip, knee, and ankle joint angles are not remarkably correlated with the long jump distance. Further, considerable positive correlations between the hip joint angle at the heel strike of the swing leg and that at the toe-off of the take-off leg ($r = 0.818$, $p = 0.004$), as well as between the ankle joint angle at the heel strike of the take-off leg and the toe-off of the take-off leg ($r = 0.745$, $p = 0.013$) (**Table 3**).

Table 3. Kinematic correlation analysis of joint angle of each stage.

Hip joint angles					
	Long jump distance	**Heel strike of the swing leg**	**Toe-off of the swing leg**	**Heel strike of the take-off leg**	**Toe-off of the take-off leg**
Long jump distance	-	−0.467	0.115	0.079	−0.358
Heel strike of the swing leg	-	-	−0.164	0.079	0.818**
Toe-off of the swing leg	-	-	-	−0.248	−0.103
Heel strike of the take-off leg	-	-	-	-	−0.067
Toe-off of the take-off leg	-	-	-	-	-
Knee joint angles					
Long jump distance	-	−0.527	−0.382	0.224	−0.333
Heel strike of the swing leg	-	-	−0.236	0.309	−0.261
Toe-off of the swing leg	-	-	-	−0.612	0.455
Heel strike of the take-off leg	-	-	-	-	−0.067
Toe-off of the take-off leg	-	-	-	-	-
Ankle joint angles					
Long jump distance	-	−0.442	−0.115	−0.103	−0.079
Heel strike of the swing leg	-	-	−0.152	0.248	0.261
Toe-off of the swing leg	-	-	-	−0.055	0.406
Heel strike of the take-off leg	-	-	-	-	0.745*
Toe-off of the take-off leg	-	-	-	-	-

*$p < 0.05$; **$p < 0.01$.

4. Discussion

In this study, kinematic analyses of female college athletes performing the long jump in an actual competition were conducted. While previous research has primarily examined the relationships between run-up velocity, take-off technique, and performance, this study highlights the transition between the heel strike of the swing leg and the toe-off of the take-off leg as a critical factor influencing long jump performance. During rhythmic movement, both horizontal velocity and resultant velocity of the center of gravity, as well as the hip joint angle, increase at the heel strike of the swing leg. However, at the toe-off of the swing leg, vertical velocity, angle, and height of the center of gravity decrease, leading to a reduction in flight distance. At the heel strike of the take-off leg, the center of gravity height drops while the ankle joint angle increases. At the toe-off of the take-off leg, both the resultant velocity of the center of gravity and the angles of the hip and ankle joints increase.

Current investigations show that the female athletes' long jump performance is essentially affected by the resultant velocity, angle, and height of the gravity center at take-off [10–14]. The results of this study indicate that the resultant velocity of the gravity center at the toe-off of the take-off leg is positively linked to the long jump distance (r = 0.673). In the former research works, the long jump distance of female athletes ranges from 5.92 m to 7.08 m, and the resultant velocity of the gravity center at the take-off is placed in the range of 7.90–8.67 m/s [10,14]. Further, the previously obtained results show that the angle of the gravity center at the take-off is in the interval 18.10°–26.40° [3,24–26], and the height of the gravity center at the take-off period takes its value in the range of 1.11–1.22 m [8,12]. Additionally, the angle of the gravity center at the take-off reaches 45° only during the long jump in place. In the actual run-up stage, the angle is usually placed in the interval of 18°–26° [26,27]. In the present scrutiny, the average long jump distance of the athletes is 5.20 m, and the average values of resultant velocity, angle, and height of the gravity center at the take-off in order are 7.25 m/s, 16.45°, and 1.11 m. Further, the obtained results reveal that the kinematics of each joint are not remarkably linked to the long jump distance. However, there is a significant positive correlation between the hip joint angle at the heel strike of the swing leg and that at the toe-off of the take-off leg, and there is a positive correlation between the ankle joint angle at the heel strike of the take-off leg and the toe-off of the take-off leg. Additionally, the results show that the angle of each joint is inter-correlated at the instant of the take-off [28]. Herein, the height of the gravity center at the take-off is comparable to that of the female athletes of other countries. The reason for the relatively short jump distance may chiefly be attributed to the slow resultant velocity and small angle of the gravity center at the take-off.

In this study, we observe in an actual competition that the transition from the heel strike of the swing leg to the toe-off of the take-off leg is the key to the long jump performance, which is generally the ability to gain fast horizontal velocity before the end of the run-up stage [12]. Furthermore, the movement pattern is adjusted in preparation for the take-off by lowering the gravity center [6]. Therefore, the transition between the heel strike of the swing leg and the toe-off of the take-off leg is the most important for the long jump [2,29–31]. Compared with previous studies, the flying stage is negatively correlated with the long jump distance, which is on average 0.08 s in this study and 0.07 s in previous studies [14]. The horizontal velocity of the gravity center and the resultant speed velocity of the gravity center at the heel strike of the swing leg are positively correlated with the long jump distance (the average in this study is 7.78 m/s and reported to be 7.79 m/s in other studies, these are associated with 7.87–8.75 m/s and 8.05–8.75 m/s, respectively) [10,12]. The vertical velocity of the gravity center at the toe-off of the swing leg is negatively linked to the long jump distance (the average in this study is 0.22 m/s, and no such data has been reported previously). The angle of the gravity center at the toe-off of the swing leg is significantly negatively correlated with the long jump distance (the average value in this study is 1.54 degrees, and no such data has been reported previously). The height of the gravity center at the toe-off of the swing leg is negatively linked to the long jump distance (the average value is 0.97 min in this study and 0.90 min in other studies) [10]. The height of the gravity center at the heel strike of the take-off leg is negatively correlated with the long jump distance (the average value is 0.96 min in this study and 0.90–0.93 min in other studies) [10,17]. The resultant velocity of the gravity center at the toe-off of the take-off leg is positively correlated with the long jump distance (the average value is 7.25 m/s in this study and 7.90–8.67 m/s in other studies) [4,5,7,10,14]. Combining the support of past research and the results of this study, we can deduce that the transition between the heel strike of the swing leg and the toe-off of the take-off leg represents a key factor in the long jump performance.

5. Conclusion

This study analyzes the key technical aspects of the long jump performed by female college athletes in actual competitions, offering valuable insights for coaches to provide video-based feedback. A particular focus is placed on the critical phase between the heel strike of the swing leg and the toe-off of the take-off leg.

In rhythmic movement techniques, it is recommended to enhance the horizontal velocity and resultant velocity of the center of gravity, along with the hip joint angle, at the heel strike of the swing leg. At the same time, the vertical velocity, angle, and height of the center of gravity decrease at the toe-off of the swing leg, shortening the flight time during the airborne phase. For optimal performance, athletes should aim to lower the height of the center of gravity and increase the angle of the ankle joint at the heel strike and toe-off of the take-off leg. Additionally, the resultant velocity of the center of gravity, along with the angles of the hip and ankle joints, should be increased.

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