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Comparative Biomechanical Analysis of the Hurdle Clearance Technique of Colin Jackson and Dayron Robles: Key Studies

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Abstract: The purpose of the study was to compare the biomechanical parameters of the hurdle clearance technique of the fifth hurdle in the 110 m hurdle race of Colin Jackson of Great Britain (12.91 s world record was set in 1994) and Dayron Robles of Cuba (12.87 s world record was set in 2008), two world record holders. Despite the athletes having performed at different times, we used comparable biomechanical diagnostic technology for both hurdlers. Biomechanical measurements for both were performed by the Laboratory for Movement Control of the Institute of Sport, Faculty of Sport in Ljubljana. A three-dimensional video analysis of the fifth hurdle clearance technique was used. High standards of biomechanical measurements were taken into account, thus ensuring the high objectivity of the obtained results. The following program was used: the ARIEL kinematic program (Ariel Dynamics Inc., Trabuco Canyon, CA, USA). The results of the comparative analysis found minimal differences between the two athletes, which was expected given their excellence. Dayron Robles's hurdle clearance was more effective, as it was characterized by a smaller loss of horizontal center of mass (COM) velocity. Robles's hurdle clearance took 0.50 s: 0.10 s for the take-off, 0.33 s for the flight phase, and 0.07 s for the landing phase. Colin Jackson completed the hurdle clearance slightly slower, as it took him 0.54 s. Jackson's take-off phase also lasted 0.10 s, his flight phase 0.36 s, and his landing 0.08 s. The two athletes are quite different in their morphological constitution. Dayron Robles is 10 cm taller than Colin Jackson, resulting in a lower flight parabola of CM during hurdle clearance of the Cuban athlete. Dayron Robles has a more effective hurdle clearance technique compared to Jackson's achievement. It can be considered that their individual techniques of overcoming the hurdle, reached their individual highest efficiency at this time.

Keywords: hurdling; biomechanics; hurdle clearance; technique analysis

1. Introduction

The high hurdle race is one of the most technically demanding athletic events, and from a biomechanical standpoint, the hurdle race is a combination of a cyclic sprint and an acyclic clearance of ten 1.067 m high hurdles. According to Bruggemman [1], the high hurdle event can be divided into the following phases: approach run to the first hurdle, clearance of the hurdles and the rhythm between hurdles, and run-out from the last hurdle to the finishing line. Therefore, a proper hurdling technique is a complicated combination of various running and jumping kinematics [2]. Additionally the hurdler must show a high level of sprinting skill, excellent flexibility in the hip joint, coordination, balance, dynamic perception, elastic power, and a high level of technical knowledge [3,4]. Thus, athletes, coaches, and professionals are constantly looking for opportunities to improve the high hurdle performance, focusing on hurdling technique with particular emphasis on the kinematics and kinetics analysis. During the last three decades, there has been a considerable amount of references concerning the analysis of hurdling technique at different levels in order to improve performance [5–11].

One of the key elements that defines a competitive result in high hurdles is the hurdle clearance technique [11–17]. When clearing a hurdle, the loss of horizontal velocity should be minimized. This was confirmed by Amara et al. [17] and Coh et al. [18], who based on their hurdle clearance analyses, claimed that horizontal velocity is one of the most crucial factors, therefore losing it should be minimized; if not, the running time will be reduced. Additionally for the fastest possible and biomechanically effective clearance of the hurdle, the athlete's take-off distance and landing distance are essential. Furthermore, Salo and Grimshaw [19] determined the optimal ratio for an efficient hurdle clearance. The ratio applies to the dependency between the take-off of the trial leg and the landing of the lead leg and should be 60:40 in flight distance. The hurdle clearance depends on other factors, especially those that define the movement trajectory of the center of mass (COM). The correct positioning of these two points determines the optimal flight trajectory of the COM, which is reflected in the flight time, which should be as short as possible [5,9,12,20]. According to Coh et al. [18] and Bubaj et al. [21] these two situations is a prerequisite for an optimal flight path of the center of mass (COM). This optimal path results in a shorter flight time. In addition to the correct position, the kinematic–dynamic structure of the take-off and landing are important, as they directly affect the speed of hurdle clearance [7,10,16,22,23]. To sum up the above considerations after Lopez et al. [24], Li et al. [22], Park et al. [25], and Amara et al. [17], the main criteria of an optimal hurdle clearance technique include horizontal velocity, height of COM at take-off, velocity of the trail-leg, flight time, height of COM at landing, and contact time.

Over the years, with the development of technology, the ability to record and film competitions in track and field has increased significantly. There has been a considerable amount of biomechanical data concerning the kinematic analysis of hurdle races at a high level of performance such as the Olympic Games, World Championships, or international meetings [24–29]. These analyses of the specialized video recording are related to the technical aspects of single event observations where competition stress and adrenaline are imposed on athletes. There has been a limited number of studies where obtaining the kinematic parameters of 110-m male hurdlers on the basis of video techniques analyses has been carried out on two consecutive races with the same competitors–hurdlers. Therefore, researchers use various video recordings in their analyses, although sometimes there are methodological differences in data collection processes. A similar procedure was used for the analysis of hurdle races of Colin Jackson and Dayron Robles, who set high standards in this athletic discipline. They were both world record holders in their 110 m high hurdle race careers and won medals at every major international competition. Colin Jackson set the world record in the 60 m hurdle race in 1993 in Sindelfingen (Germany) with a time of 7.30 s. A year later, he improved the world record in the 110 m hurdles with a time of 12.91 s, still considered the seventh-best time in the history of this athletic discipline. Dayron Robles also improved the world record in the 110 m hurdle race (12.87 s) in 2008 in Ostrava (Czech Republic), which is considered to be the second-best result of all time in high hurdle races.

These studies were conducted to analyze comparable data held by the Laboratory for Movement Control of the Institute of Sport, Faculty of Sport in Ljubljana. Biomechanical measurements of both athletes were performed at different times, but under comparable conditions with similar measurement technologies. In both cases, a kinematic analysis of the fifth hurdle clearance technique was used. High standards of biomechanical measurements were taken into account, thus ensuring the high objectivity of the obtained results. We are aware that the study would have been even more valuable had we been able to analyze a greater number of obstacle clearances, but this was not possible due to organizational and technical constraints. The main aim of the study was to identify, analyze, and compare the essential kinematic parameters of the hurdle clearance technique at hurdle 5 of two athletes who have set the highest standards of biomechanical rationality of hurdle clearance in 110 m high hurdle races.

2. Materials and Methods

2.1. Participants

In this experiment, the participants were two world class hurdlers: Colin Jackson (body mass 75 kg, and height 182 cm) from Great Britain and Dayron Robles from Cuba (body mass 79 kg and height 191 cm). Both competitors specialized in 110 m hurdle, and were or are world record holders in 110 m hurdles. Some more personalized and anthropometric data of both athletes are shown in Table 1. The participants provided informed consent and were informed of the protocol and procedures for the study prior to the official video recording. The selection of athletes to conduct the experiment was specific and dependent on the possibility of making a video recording with its entire comprehensive procedure during an international meeting, and above all dependent on the level of participants in these competitions. Due to the fact that the experiment concerns the analysis of the hurdle technique for only two competitors, it can be qualified as a case study—the work reports scientifically sound experiments and provides a substantial amount of new information. The study was approved by the Human Ethics Committee of the University of Ljubljana.

Table 1. Basic anthropometric and biographical data of Colin Jackson (Great Britain) and Dayron Robles (Cuba).

Parameters	Colin Jackson	Dayron Robles
Date of birth	1967	1986
Body height (cm)	1.82	1.92
Body mass (kg)	75	79
Body Mass Index (BMI)	22.64	21.43
Best result (s)	12.91 *	12.87 **
Experimental result (s)	13.47	13.00
100 m best results (s)	10.29	10.71

BMI (Body Mass Index), * World Record in 1993, ** World record in 2008.

2.2. Experimental Design

The experiment design used was a comparison of dynamic and kinematic variables between two 110 m hurdles races at the segment between hurdles 4 and 5 and hurdle clearance of two world record holder. Both recordings of hurdles took place during regular international athletics competitions, although in two different places and two different years. These two conditions forced the experiment to match two different race recording methodologies. The hurdle races of Jackson and Robles were both recorded using two cameras each, although of different resolutions of 50 Hz frames per second and 100 Hz per second, respectively. From a methodological point of view, this may be a significant difference, but the conditions of variability were respected when processing data. In order to avoid the errors involved in analysis, real measurements were recalculated, taking into account the measurement error, which actually means that they corresponded (e.g., 50 Hz means 0.04 s between frames, so a hurdle clearance time of 0.5 s vs. 0.54 s represents a single frame). In both analyses the model of Dempster [30] was used for the calculation of the body's COM and the kinematic program ARIEL (Ariel Dynamics Inc., Trabuco Canyon, CA, USA) for the digitization was applied.

2.3. Procedure of Measurements—Colin Jackson

Colin Jackson's biomechanical analysis was carried out on 28 June 2002, at the International Meet in Velenje (EA Classic). His finish time was 13.47 s. The weather conditions were optimal; the outside temperature was 27 °C with a wind speed of + 0.2 m/s. Authorization to perform the experiment was approved by the Slovenian Track and Field Association. Biomechanical measurements were performed by a team of experts from the Laboratory for Movement Control of the Faculty of Sport in Ljubljana. Two synchronized cameras, namely Sony DSR-300-PK DVCAM Camcorders with Fujinon 17x lenses, were located at the main stands (the zone of hurdle 5) and operating at 50 Hz (shutter speed: 1/1000) were used to film the races. To record all kinematic parameters, the cameras were set at an angle of 120 to the direction of the moving hurdler in the segment between hurdles 4 and 5 (Figure 1). The zone of the 5th hurdle was calibrated with a calibration cube, one at the beginning of hurdle 4 and one at the end of hurdle 5. A 15-segment Dempster's model [30] and the ARIEL kinematic program (Ariel Dynamics Inc., Trabuco Canyon, CA, USA) were used to calculate the center of mass.

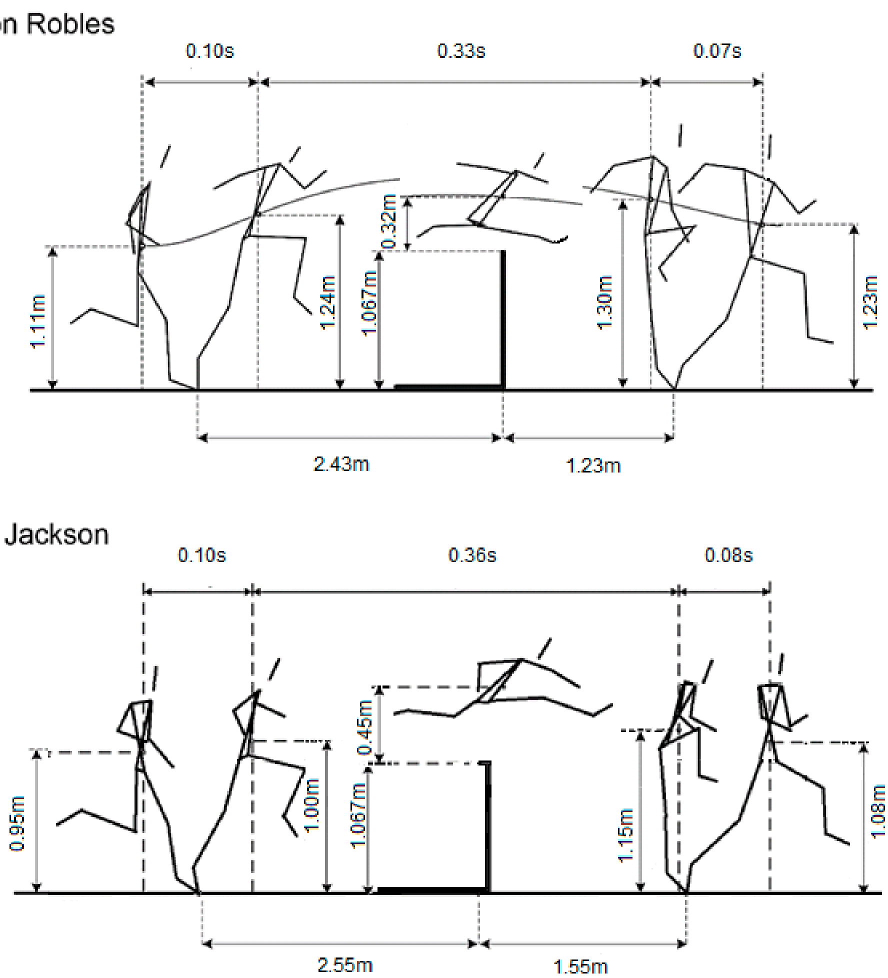

Figure 1. Comparison of biomechanical parameters of hurdle clearance.

2.4. *Procedure of Measurements—Dayron Robles*

Biomechanical analyses of Dayron Robles's 5th hurdle clearing technique was performed at the 2011 IAAF World Challenge—Zagreb International Race. Weather conditions were optimal; the outside temperature was 23 °C, and the wind speed was −0.2 m/s. Authorization to perform biomechanical measurements was obtained from the Technical Delegate of the European Athletics Federation and the Organizing Committee of the competition. The running track lane in the zone of the 5th hurdle was covered by two Casio high-frequency digital Casio EX-F1 512 × 384 (300 fps) sampled down to 100 fps cameras (Casio Computer Co., Ltd., Tokyo, Japan), which were interconnected and synchronized. The shutter speed of the Casio cameras was 1/300 s. The cameras were set perpendicular to the zone of the 5th hurdle (running hurdler) at an angle of 90°. The zone of the 5th hurdle was calibrated with a 2 m × 2 m × 2 m reference frame, within which eight points were measured. Data processing utilized an APAS computer system for 3D kinematic analysis (Ariel Performance Analysis System). Digitization of a 15-segment athlete body model was carried out, defined by 15 reference points [30] The point coordinates were smoothed with a 14 Hz digital filter. The center of mass (COM) was calculated from the digitized points based on Dempster's (1955) model of determination of COM via the ARIEL kinematic program (Ariel Dynamics Inc., Trabuco Canyon, CA, USA).

3. Results

The difference in body weight between competitors was only 4 kg. An even greater difference was in body height and was 10 cm in favor of Robles. Both measurements significantly differentiated hurdlers in terms of a measure of body fat (the ratio of the weight of the body in kilograms to the square of its height in meters), which was 1.21 in favor of Robles (Table 1). The time difference between those two world records is 0.04s. Jackson set his world record at the age of 26 and Robles at the age of 22. The age difference between competitors on the day of the experiment was approximately 10 years in favor of Jackson, and Robles obtained a better result by 0.47s in the 110 m performance.

Based on biomechanical analyses (Table 2), the following results were obtained: Robles's total stride length was 3.66 m, and the stride was completed in 0.33 s, while Jackson's stride length was 3.67 m, and it was slightly slower, lasting 0.36 s. During hurdle clearance, Dayron Robles reached the highest COM point at 1.38 m (0.32 m above the height of the hurdle), which corresponded to 72.2% of his body height. Colin Jackson reached the COM trajectory point at 1.52 m (0.45 m above the hurdle height), which was 83.4% of his height. The difference between the lowest COM point in the eccentric phase of the take-off was 1.11 m for Robles and 0.95 m for Jackson; and the highest COM point during the flight phase was 1.387 m for Robles and 1.517 m for Jackson. The height of the COM at the end of the concentric phase of take-off for Robles was 1.24 m and 1.08 m for Jackson.

Table 2. Biomechanical variables of the clearance of the fifth hurdle.

Variables	Colin Jackson	Dayron Robles	Difference	Δ (%)
Horizontal velocity 4 H–5 H (m/s)	9.14	9.18	0.04	0.43
Take-off (braking phase)				
Horizontal velocity of COM (m/s	8.81	8.70	0.11	1.25
Vertical velocity of COM m/s	–0.43	–0.70	0.37	62.79
Velocity resultant of COM (m/s	8.82	8.73	0.09	1.03
Height of COM (m)	0.95	1.11	0.16	16.84
Foot to hurdle distance (m)	2.09	2.43	0.34	16.26
Take-off (propulsion phase)				
Horizontal velocity of COM (m/s)	9.11	9.00	0.11	1.21
Vertical velocity of COM (m/s)	2.35	1.80	0.55	23.41
Velocity resultant of COM (m/s)	9.41	9.18	0.23	2.45
Height of COM (m)	1.08	1.24	0.16	14.81
Push-off angle (°)	72.9	78.7	5.80	7.95
Contact time (s)	0.10	0.10	0.0	0.0
Flight				
Flight time (s)	0.36	0.33	0.03	8.34
Height of COM above the hurdle (m)	0.45	0.32	0.13	28.89
Maximal height COM (m)	1.44	1.52	0.08	5.55
Landing (braking phase)				
Horizontal velocity of COM m/s	8.77	8.80	0.03	0.34
Vertical velocity of COM (m/s)	–1.02	–1.00	–0.02	1.97
Velocity resultant of COM (m/s)	8.84	8.86	0.02	0.22
Height of COM (m)	1.15	1.30	0.15	13.04
Foot to hurdle distance (m)	1.58	1.23	0.35	22.16
Landing (propulsion phase)				
Horizontal velocity of COM (m/s)	8.41	9.35	1.06	11.17
Vertical velocity of COM (m/s)	–1.32	–1.00	–0.32	24.25
Velocity resultant of COM (m/s)	8.53	9.40	1.13	10.19
Height of COM (m)	1.06	1.23	0.17	16.03
Contact time (s)	0.08	0.07	0.01	12.50

4. Discussion

The entire process of hurdle clearance took 0.50 s for Robles; it took 0.10 s for take-off, 0.33 s for the flight phase, and 0.07 s for the landing phase. Meanwhile, Colin Jackson completed the hurdle clearance a little more slowly, as it took him 0.54 s. Jackson also spent 0.10 s for take-off, 0.36 s for the flight phase, and 0.08 s for the landing phase. For comparison, the measurement of Amara [23]—a medium level athlete (13.90 s at 110 m hurdles) showed differences in the abovementioned parameters of 0.60 s, 0.36 s, 0.21 s, and 0.12 s (respectively for each variable). Jackson's slower clearance of the hurdle is associated with a higher rise in his COM above the hurdle and a longer landing distance over the hurdle, extending both the flight phase and the shock absorption phase. A slower hurdler [30] had a similar problem; his excessive height of the vertical COM displacement together with a high take-off angle had a negative impact on the time to clear the hurdle. The difference in the flight parabola between the two athletes can be attributed mainly to the difference in their height and the difference in their functional abilities. Based on the kinematic parameters of the parabola, we can, therefore, conclude that Dayron Robles has a more rational hurdle clearance technique (Figure 1).

The take-off distance for Robles was 2.43 m, which was 66.4% of the total clearance length over the hurdle. For Jackson, the take-off distance was 2.09 m, which was 57.0% of the total length of clearance. Jackson's landing distance was 1.58 m (43.0% of his total stride length), while Robles's was 1.23 m (33.6% of his total stride length). It can be compared with some other studies [10,30], which indicate that the optimal ratio between take-off spot and landing place should be 40–60%, which is comparable with Amara's [17] findings (i.e., 58:42). This ratio was confirmed by previous researchers [8,18,24,28,31,32], which indicated that take-off distance should range from 2.04 cm to 2.31 cm. In turn, the landing distance was shorter. We can identify two different hurdle clearance strategies. Robles has a faster hurdle clearance; his take-off is elongated, and his landing is closer to the hurdle. The duration of Robles's flight phase is 0.33 s, and that of Jackson is 0.36 s. A technical model of When [33] indicated that the optimal over the hurdle time should range between 0.30 and 0.33 s for a world class hurdler. This confirms the importance of the take-off (the angle between the top of the foot and the hip) and landing distances in high hurdler races, as was previously mentioned by Coh and Iskra [31] and Lopez at el. [24].

In the concentric phase, Robles had a take-off angle of 78.7 °, and Jackson's was 72.9 °. The COM velocity resultant during the braking phase of the take-off was 8.73 m/s for Robles and 8.82 m/s for Jackson. This velocity resultant of COM is defined as the vector sum of the vertical COM velocity (0.70 m/s for Robles, –0.43 m/s for Jackson) and horizontal COM velocity (8.70 m/s for Robles and 8.81 m/s for Jackson). It changes until the last contact of the take-off when it measured 9.18 m/s for Robles and 9.41 m/s for Jackson. Robles's vertical COM velocity at that time was 1.80 m/s, and Jackson's was 2.35 m/s; their horizontal COM velocities were 9.00 m/s and 9.11 m/s, respectively. The COM horizontal velocity during take-off thus increased by 0.30 m/s for both Robles and Jackson. The relative increase in the horizontal velocity of COM for Robles was 3.30% and 3.29% for Jackson (Figure 2). For both athletes, the duration of their take-off was the same. Robles's COM height during take-off increased by 0.13 m, equal to Jackson's (Figure 1). It is comparable with data of Amara [17], Li and Fu [34], and Lopez at el. [24], who claimed that during take-off (propulsion phase), the average height of the COM should be around 1.12 m.

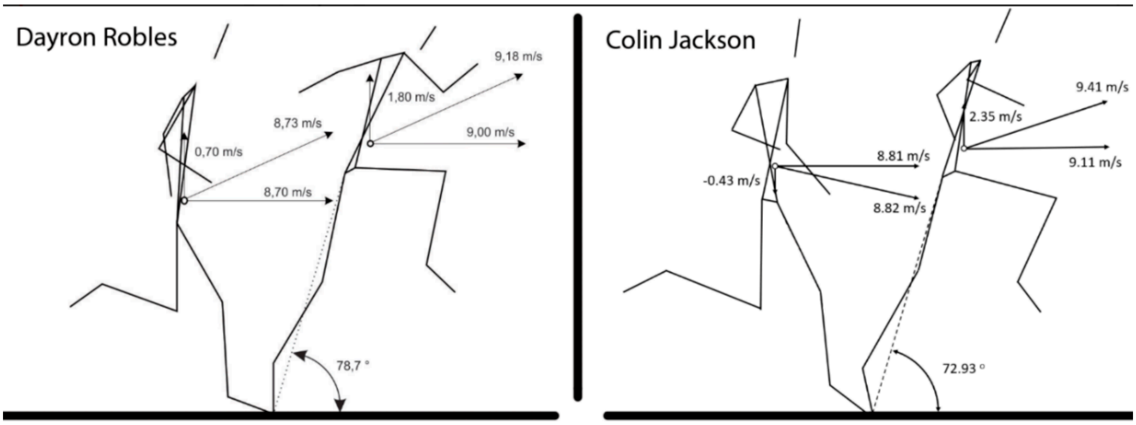

Figure 2. Comparison of the biomechanical parameters of take-off before the hurdle.

The transition between hurdle clearance and the sprint between hurdles is dependent on the landing phase. For Robles, the horizontal velocity at landing was 8.80 m/s, which means that the horizontal velocity decreased by 0.20 m/s (2.2%). For Jackson, the horizontal velocity decreased by 0.34 m/s (3.7%). During the landing phase, Robles's height of COM decreased by 0.07 m (5.4%) and 0.09 m (7.8%) for Jackson. The short duration of the landing phase (0.07 s for Robles and 0.08 s for Jackson) indicated a high level of reactive power [35] for both athletes (Figure 3), and an efficient transition to sprinting between hurdles [4,36].

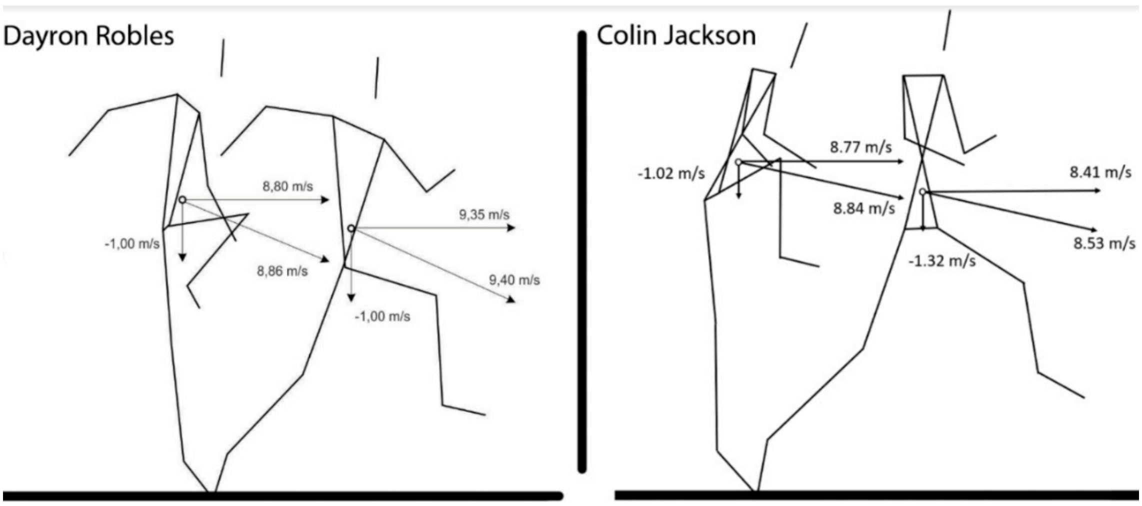

Figure 3. Comparison of the biomechanical parameters of the landing.

For Jackson, the reduction in the horizontal velocity of COM was greater than that of Robles, and the height of his center of mass (COM) was lower at landing, so it can be concluded that Robles has a slightly more biomechanically rational hurdle clearance technique. In addition, our results do not contradict the research of Amara [23], who claimed that the vertical component of COM velocity and the lead-leg/trail-leg at take-off and at flight phase constituted key factors of optimum hurdle clearance. According to Amara [17,23] and Shibayama et al. [37], in addition to the take-off angle, the knee and the hip angles are very important in high hurdles clearance, as also found in previous studies done by Coh [18,38], Xi et al. [22], Bubaj [21] and Sidhu [39]. Liu [40] just confirmed this statement and additionally indicated that the flight-phase duration is also defined by the takeoff angle, which should be lower.

5. Conclusions

In the present study, we analyzed the rationality of the 110 m hurdle clearance technique of Colin Jackson and Dayron Robles, using diagnostic technology for kinematic analysis. Both athletes have roughly the same personal record in the 110 m hurdle races (Jackson 12.91 s, Robles 12.87 s). The two hurdlers are quite different in morphological constitution, with Dayron Robles being 10 cm taller than Colin Jackson. Based on the results obtained, it can be concluded that Dayron Robles has a more effective hurdle clearance technique. It is characterized by a smaller loss of horizontal velocity of COM during clearance, a better COM flight parabola over the hurdle, and a smaller difference between the hurdle height and the height of the highest COM point, compared to Jackson's achievement. It proves that their hurdle clearance efficiencies differ but depend on the same kinematic parameters. Therefore, it can be considered that their individual technique of overcoming the hurdle their reached individual highest efficiency at this time. On this basis, we can also assume that the difference in overcoming one hurdle (the fifth) accumulated in the remaining hurdles until the end of the race, which reflects the final results of the races. Here Robles obtained a better running time in the 110 m hurdles.

6. Practical Application

From a practical point of view, based on some of the spatiotemporal parameters presented in the present analysis, there are some high hurdle common performance indicators. In order to optimize high hurdle performance with special regard to clearance hurdle movement performance, lower vertical displacement of COM, combined with right angle of take-off and short contact-time at the take-off and landing phases must be considered. These elements help improve a quick turn between horizontal and vertical velocity of forward propulsion and fast return of the trail leg at landing. To improve these indicators, appropriate training needs to be applied. It should consider high technical proficiency training and first of all activities which improve a higher rate of force development.

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